RESPONSE OF A TROPICAL LEGUME-GRASS ASSOCIATION TO SYSTEMS OF GRAZING MANAGEMENT AND LEVELS OF PHOSPHORUS FERTILIZATION

BY

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Dedicated to my wife, Maggie,
my daughters, Alexandra and
Carolina, my father and to
the memory of my mother

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TO SYSTEMS OF GRAZING MANAGEMENT AND LEVELS OF
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By

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Chairman: Dr. G. O. Mott
Major Department: Agronomy

A legume-grass pasture composed of glycine [Neonotonia wightii (R. Grah ex Wightii and Arn.) Lackey], centro (Centrosema pubescens Benth.), guineagrass (Panicum maximum Jacq.), and elephantgrass (Pennisetum purpureum Schumach.) was evaluated in a grazing trial from May 1978 to June 1980 at the Estacion Experimental Tropical Pichilingue, Instituto Nacional de Investigaciones Agropecuarias (INIAP), Quevedo, Ecuador.

The main objectives of the study were (a) to determine the effects of length of grazing period (X_1), length of rest period (X_2), grazing pressure (X_3), and levels of P fertilization (X_4) upon the pasture mixture; (b) to determine the proper grazing management to attain the optimum legume contribution; and (c) to measure the pasture response in terms of dry matter production and botanical composition.

Grazing periods studied were 1, 7, 14, 21, and 28 days; rest periods were 0, 14, 28, 42, and 56 days; grazing pressures were 1.6, 3.3, 5.0, 6.6, and 8.3 kg DM on offer/100 kg body weight; and

levels of fertilizer were 0, 100, 200, 300, and 400 kg ha^{-1} of superphosphate. To cover the five levels of the complete factorial (5^4), a modified non-rotatable central composite design made up of 41 treatment combinations was used.

The response variables included aerial biomass (DM), available forage (DM), grass yield (DM), legume yield (DM), yield of weeds (DM), percentage grass, and percentage legume. A double-sampling procedure was used for estimating pasture production and botanical composition.

Rest periods and grazing pressures had the greatest effects on all response variables. Aerial biomass, available forage, grass yield and grass percentage were increased by longer rest periods and by lower grazing pressure. Legume yield and legume percentage were decreased by long rest periods and by low grazing pressure. Short rest periods and high grazing pressures resulted in high yields of weeds. Medium levels of both rest periods and grazing pressure were required for high forage dry matter production and for high legume yield.

The other two variables, days grazing and levels of phosphorus fertilization, had negligible effects upon the response of the pasture sward.

CHAPTER I
INTRODUCTION

Ecuador, with an area of 273,670 km^2 is located in the northwestern part of the South American continent. The dominant topographical features are two parallel ranges of the lofty Andes mountains that separate the fertile littoral lowland on the west and the more extensive and less fertile lowland of the Amazon Basin on the east.

The diversity of natural features of the littoral region is very great due to its multiple climatic conditions, soils, forms of vegetation, and settlement patterns which set it apart from the more homogeneous Sierra and Oriente regions.

In the littoral, about 2,500,000 ha are considered as pasture land, supporting 2,875,000 head of cattle giving a carrying capacity of 1.12 animals ha^{-1}.

The seasonal pattern of rainfall distribution and the low soil N levels are factors restricting forage production and quality during the wet-dry seasons. It is well known that cattle production is limited by the feed supply during the dry season, while in the wet season, there is abundance of forage.

Pastures are mainly planted to guineagrass (*Panicum maximum* Jacq.) or elephantgrass (*Pennisetum purpureum* Schumach.), with other species making up a very small portion of the total hectarage.

At present, there is a growing interest in the establishment and utilization of tropical grass-legume mixtures for animal production. There are many advantages to having legume components in the

pasture. They increase or maintain soil fertility due to their ability to fix N, improve the quality of the diet grazed by the animals, provide better seasonal distribution of the forage throughout the year, especially where alternate wet-dry seasons occur. Therefore, a system which combines adequate grazing management practices with high-yielding grasses and legumes growing in mixtures which provide feed during the whole year is needed to increase carrying capacity and the final output of the land.

The objectives of this research were

1) To determine the response of a tropical legume-grass mixture to various treatment combinations of grazing management factors length of grazing period, length of rest period, grazing pressure, and levels of phosphorus fertilization.
2) To determine the proper management strategy for adapted forage species to attain the optimum legume contribution as a component in the mixture, and
3) To measure the results of legume-grass mixture in terms of aerial biomass, available forage, and botanical composition of the forage on offer.

CHAPTER II
LITERATURE REVIEW

In tropical regions animal production on pastures is dependent upon the quality and quantity of forage available throughout the year. In the humid tropics the seasonal growth of pastures is greatly influenced by the wet and dry periods. At the beginning of the wet season very rapid growth occurs and frequently a large amount of forage accumulates. As the season progresses the rate of growth decreases rapidly and approaches zero during the dry season. The concentration of nitrogen and minerals is relatively high at the beginning of the wet season and also falls rapidly as the season progresses. In addition there is a progressive increase in fiber and decrease in digestibility from the beginning of the wet season through the remainder of the year (Paladines and de Alba, 1963).

Some tropical pasture species seem to be well adapted to extreme environmental conditions; however, their potential to supply feed for cattle production may be limited not only by seasonal changes but also by soil fertility (Tergas, 1968), mechanisms of adaptation (Gartner et al., 1974), and grazing management (Mott, 1960; Evans, 1970; Stobbs, 1969).

The Tropical Forages

Panicum maximum Jacq. has been described by Humphreys (1980) and Bogdan (1977) as a densely tufted perennial grass with relative drought and poor soil tolerance. It is of high nutritive value when young and combines well with other tropical pasture species (Hudgens, 1973;

Chavez, 1974; Rolando, 1974). It is indigenous to tropical Africa where it is dominant over large areas, particularly under humid and subhumid conditions. In the coastal area of Ecuador it is known as guinea, cauca, saboya, chilena. Betancourt (1969) indicated that guineagrass was the most widespread pasture grass in the lowlands of Ecuador. Acosta-Soliz (1967) reported that this grass grows from sea level up to 1400 m.

Guineagrass is very popular because of its adaptation to the dry season, resistance to fire, high production of forage, capability of establishment by seed or by division of plant crowns, and finally due to its ability to persist under heavy use and abuse (INIAP, 1980).

Recently the Instituto Nacional de Investigaciones Agropecuarias (INIAP) of Ecuador has tested 124 introductions of guineagrass in small grazing trials, mainly for adaptation and persistence. New cultivars will be released to the farmers as soon as sufficient seed is available for large scale use (INIAP, 1979).

Pennisetum purpureum Schumach, elephantgrass, is a tall-growing species, up to 5 m in height. It has been described by Bogdan (1977), Correa (1926), and McIlroy (1972).

Acosta-Soliz (1967) and INIAP (1980) stated that elephantgrass grows from sea level up to 2200 m in the warm valleys of the Sierra region. In Ecuador it is mainly used as a pasture grass with some farmers reporting pastures up to 40 years old still under grazing conditions. Under cutting frequencies of 45 days it produces up to 80 tons DM ha^{-1} yr^{-1} when receiving 400 kg of N and irrigation during the dry season (INIAP, 1972). There are three cultivars which are

in widespread use in the lowlands of Ecuador. They are 'common' for grazing, 'Hybrid 534' and 'Mexican' for cutting.

Centrosema pubescens Benth, centro, a true tropical legume has been described by Humphreys (1980) as a creeping, twining perennial legume native of South America. Grof (1970) reported that the genus Centrosema contains about 70 species growing naturally in the tropical areas of Central and South America. Moore (1962) stated that this tropical legume grows well in humid areas and must be considered as a basic component of pastures under these conditions. Studies conducted at Pichilingue, Ecuador, by Hudgens (1973), Chavez (1974), Rolando (1974) and INIAP (1980) indicated that this legume performs well in association with guineagrass and it is also highly persistent under grazing and produces large amounts of seed (Farfan, 1974). In the last few years 132 native ecotypes of Centrosema have been selected and tested in Ecuador. A few of these have been distributed to farmers and are showing some advantages over the Australian commercial cultivars such as higher DM yield, better tolerance to insects and disease, and better adaptation to Ecuador conditions (INIAP, 1979).

Neonotonia wightii (R. Grah. ex Wight and Arn.) Lackey, glycine, also known as perennial soybeans, has been described by Humphreys (1980) as a perennial plant, slender, twining, and with long stems having some capacity for rooting at the nodes.

Glycine was first introduced into Ecuador in 1966, but it was not used in pastures until 1973 when it was shown to be one of the best legumes for humid and subhumid areas. Three cultivars have been distributed to farmers and these were selected for persistence,

adaptability, seed production and disease and insect resistance. These cultivars are 'Malawi' for lower altitudes, 'Cooper' for medium altitudes up to 1200 m and 'Tinaroo' the highest forage yielder grows well from 50 to 1800 m of altitude, producing large amounts of seed from 800-1500 m (INIAP, 1979).

Persistence of Tropical Legume-Grass Associations

Serrao (1976) suggested that the first requirement for successful use of high-yielding pasture legumes was their adaptation to local climatic conditions. Secondly, nutrient requirements must be met to insure high yield and maintenance. And finally, they must persist under heavy grazing to secure a long lasting beneficial contribution to the companion grass, to the soil, and to the grazing animal. Gomez (1978) has suggested some other factors which can affect the persistence of tropical legumes when they are growing in association with grasses. Among the most important are (1) environmental factors such as light, temperature and moisture; (2) growth habits of each species growing in the mixture; (3) nodulation ability and capacity for nitrogen fixation; (4) edaphic factors such as pH, nutrient availability, form of supply; (5) frequency and intensity of defoliation by grazing animals; (6) ability to survive during long drought periods; (7) seed production capacity; and (8) pest and disease tolerance. Ludlow and Wilson (1970) reported that tropical grasses achieve up to three times the photosynthetic rate when compared with tropical legumes. This characteristic obviously gives ecological advantages to C-4 grasses, affording them the opportunity to grow faster, dominate

and even exclude the C-3 legumes from the mixture. Tow (1967) showed that green panic (Panicum maximum var trichoglume) was much more productive at all light intensities and higher root temperatures than glycine when both species were tested under controlled environmental conditions. Roberts (1974) also studied some of the above factors and included some others which are associated with the stability of legume-grass mixtures. These were palatability of the grass and legume, maximum height of the grass, legume ability to grow under the shade projected by the companion vegetation, and the capacity to withstand trampling. He also suggested that continuous grazing helps the legume to compete more effectively with the grass due to more frequent defoliation than under a rotational grazing system. Kretschmer (1974) reported that in general grasses have a better range of adaptation and also a more vigorous growth habit that allows them to compete always at an advantage over most tropical forage legumes. Lack of legume persistence is attributed to the use of unadapted species and cultivars, improper or no fertilization, incorrect rhizobium and overgrazing (t'Mannetje, 1978).

Growth habit and leaf morphology of species that compose a mixture are important characteristics which have direct effects upon compatibility and persistence, due especially to light interception ability of each individual species. Santhirasegaram (1976) in the humid tropic of Peru reported that in a well-managed guineagrass-centro pasture, the persistence of the legume was due to its viney growth habit enabling it to climb the stems and leaves of this tall and aggressive grass. Thus, the legume can intercept sufficient

solar radiation. They also suggested that the ideal type of twining tropical legume should have a strong stoloniferous or rhizomatous growth habit in order to withstand frequent defoliation and heavy damage by grazing animals. Whiteman (1969) pointed out that frequent defoliation results in low yields of twining legumes such as glycine and Siratro, whereas slight defoliation or absence of defoliation results in a higher contribution of the legumes to the total pasture production. In Africa, Draolu and Nabusin-Napulu (1980) studied the effect of cutting intervals of 3, 6, 12, and 24 weeks and cutting heights of 3.8, 7.5, 15.0, and 30.0 cm in mixed swards of guinea-grass and *Stylosanthes guianensis*. They concluded that DM production was greatly reduced under the lowest and most frequent cutting treatment. The amount of legume in the mixture also decreased as the cutting intervals were increased and the legume was particularly sensitive to close defoliation. In Australia, McIvor et al. (1981) found the same linear tendency with *Desmodium intortum* and *Setaria sphacelata* mixtures under different cutting heights of 8 and 20 cm and cutting intervals of 3, 6, and 9 weeks. The growth response of desmodium was markedly depressed at the lowest cutting height of 8 cm and the shortest cutting interval of 3 weeks. They concluded that cutting at the height of 20 cm at intervals of 6 to 9 weeks was necessary for the persistence of the desmodium in the mixture. Bryan et al. (1971) indicated that the short growth habit of the tropical legumes *Stylosanthes humilis* and *Lotononis bainesii*, which may be shaded by taller companion grasses, benefits from heavy grazing pressure which allows light penetration into the canopy. They also

concluded that the dominance of climbing legumes such as glycine and Siratro is generally enhanced by light grazing pressure and also by long intervals between grazing periods.

Grazing experiments conducted in the wet tropics of Ecuador by Berrezueta (1975), Chavez (1974), INIAP (1979) and Zapata (1981) showed that guineagrass-centro pastures and guineagrass-glycine pastures are very persistent and productive mixtures even if heavy grazing pressures are applied. They also observed that rest periods of over 28 days during the wet season favored the companion grass and reduced drastically the amount of legume. Finally they concluded that the guineagrass is dominant, especially at the beginning of the wet season, probably due to the large amount of nitrogen stored in the organic matter during the six to seven months dry season. The high growth rate of this grass decreases slowly and reaches the lowest rate of growth at the end of the dry season while the legumes appeared to be more productive during the dry season. The legumes are the main source of feed for the grazing animals during the dry season. A study of eight grass-legume associations was also made from 1971 through 1973 using grazing animals. Paragrass (*Brachiaria mutica*)-glycine and guineagrass-centro mixtures were shown to be the most compatible and the best accepted by the grazing animals, while tropical kudzu (*Pueraria phaseoloides*) and *Calopogonium mucunoides* were unpalatable species, a characteristic that could determine the dominance of this species over the companion grasses (INIAP, 1974).

Response to Nutrients

Legumes are generally more sensitive to soil factors than other pasture plants, particularly grasses. This sensitivity of legumes emphasizes the importance of understanding the effects of these limitations in tropical conditions. Russell (1978) suggested that improving the growth of legumes in low fertility soils could be approached in two ways: (1) by amelioration of soil conditions through the use of fertilizers or amendments, and (2) by the selection of legume cultivars or genera which are more tolerant to the limiting conditions. There seems to be a general consensus that N and P, in that order, are the plant nutrients that are more often deficient in the tropics (Fox, 1979).

The amount of N fixation, nodulation, persistence, and yield of tropical forage legumes may be affected by the soil pH and also by the availability of plant nutrients. Manhaes and Dobereiner (1968) and Fox et al. (1974) reported that for good legume establishment, adequate amounts of available P were required, especially during the nodulation stages. These authors determined that glycine required 60 ppm of P_2O_5 in the soil solution during the establishment phase. This requirement decreased after the second cutting. In Australia, Andrew and Robins (1969) determined the critical P concentration in the tops associated with maximum plant growth as being the critical levels. These were 0.16 and 0.23% for centro and glycine, respectively. For adequate plant uptake, $H_2PO_4^-$ ions in the soil solution should be between 0.07 to 0.2 ppm. According to Sanchez (1977) some

tropical legumes tolerant to low available soil P either absorb P at a faster rate or are able to tranlocate it to the tops more rapidly than do species not tolerant to low P availability (Salinas and Sanchez, 1976; Andrew, 1978). Considerable yield response to P fertilizers was reported by Jones and Freitas (1970) with four tropical legumes (*Stylosanthes guianensis*, centro, glycine, and Siratro). Similar results were obtained by Franca and Carvalho (1970) in greenhouse studies, using five tropical legumes (glycine var 'Common,' glycine var 'Tinaroo,' Siratro, centro, and *Pueraria phaseoloides* var 'Javanica' Benth.). In both cases the P deficiency was reflected in decreased nodule weight and N fixation capability. Snyder and Kretschmer (1974) obtained small linear increases in dry matter yields of Siratro, 'Cook' stylo, centro, and *Desmodium heterocarpon* (L.) DC when lime was applied in 500 kg ha^{-1} increments up to 3000 kg ha^{-1} without P fertilization. When the same levels of lime were used together with 45 kg ha^{-1} of P the response in yield was linear up to 2000 kg ha^{-1} of lime and curvilinear thereafter. Estimation of P requirements for plant growth should be based on the amount of P needed to give at least 95% of maximum growth (Ozanne and Shaw, 1976). Neme and Lovadini (1967) working with glycine found that a combination of 120 kg of P_2O_5 plus 6 metric tons of lime ha^{-1} gave a large increase in yield. Werner (1979) reported substantially increased yields of centro to P and K fertilization. Palacios (1976) in Ecuador found that centro responded positively to P fertilization during the establishment period, but yield response was not related to the amount of P applied to the soil during the sowing time. Falade

(1975), comparing six levels of P (0, 15, 30, 60, 120, and 180 mg/ 2 kg of soil/pot), found that P concentration in guineagrass and elephantgrass was increased with the addition of P. The same response was reported by Vicente-Chandler (1975) from Puerto Rico, where 80% of the maximum dry matter production of pearl millet [Pennisetum americanum (L.) K. Schum.] was obtained when soil pH was raised to 5.5 and 115 ppm of P were added. At a pH of 4.8, twice as much P was needed to produce the same forage yield. Fox (1979) reported that the standard P requirement was a relative soil requirement, not an absolute plant requirement. Fox et al. (1974) from Hawaii reported large increases in P uptake by several pasture species, once soils which had high P-fixing capacities were limed to pH 5.0 and 6.0. Phosphorus requirements of soils can range from zero to more than 2220 kg P ha^{-1}.

After N and P, S is considered by many as the next most important element needed for tropical legume growth. Tergas (1977) noted the significance of S on the growth and nodulation of several different tropical forage legumes. Siratro and centro dry matter and nodule weight increased as S was increased. Sanchez (1977) mentioned that S deficiencies are widespread throughout the tropics and that some pasture legumes are more susceptible to S deficiency than most grasses.

Medina (1969) reported S deficiencies in some crops growing in the littoral region of Ecuador. Also, a strong response from guineagrass, paragrass, glycine, and centro was observed when S was applied alone or supplied by the ordinary superphosphate or by ammonium sulphate (INIAP, 1980).

In the tropics, where there are well defined wet and dry seasons, rainfall plays an important role in the uptake and nutrient content of tropical forage species. Blue and Tergas (1969) reported a drop in N, P, and K contents during the dry season; likewise a decrease of nutrient content during the wet season was found and it was postulated to be due to translocation of nutrients to the roots. Rapid growth during wet seasons may result in trace mienrals being translocated to plant tops where they are rapidly diluted with aerial tissue causing deficiency symptoms in older tissues (Reuter, 1975).

Micronutrients can play an important role in tropical legume pastures growth, mainly because of their function in several enzyme systems and in N-fixation by rhizobium-legume associations. Werner et al. (1975) studied tropical legume response to the micronutrients Mo, Cu, Zn, B, Mn, and Co in the form of FTE BR-10 and also in the salt form. Using three tropical legumes planted in pots, they observed visible symptoms of Mn toxicity on glycine and B toxicity on stylo. This work emphasizes that there is a narrow range between deficient and toxic levels of some micronutrients.

Medina (1969) found some micronutrient deficiency symptoms in some tropical crops growing in the Quevedo area. He reported that B, Zn, and Fe were the most deficient elements. INIAP (1978) found that at the beginning of the rainy season, the period of most rapid growth for grasses, such as paragrass, Zn deficiency symptoms were evident but these disappear in two or three weeks. Molybdenum also has been recognized as an essential element for legume growth especially for establishment and maintenance. Some authors have suggested that this

element is necessary for development of enzymes related to N fixation, nitrate reduction and legume nodulation (Andrew, 1978; Epstein, 1972).

Animal Productivity

In Pichilingue, Ecuador, Zapata (1981) observed that liveweight gain of steers grazing on common guineagrass, improved Guineagrass *Brachiaria humidicola*, and improved guineagrass-glycine pastures were, in the order given, 0.645, 0.678, 0.741, and 0.857 kg animal^{-1} day^{-1} and an annual liveweight gain of 338.9, 421.9, 458.3, and 540.4 kg ha^{-1}, respectively. The same author also noted a difference in liveweight gain due to the breed of animal, being 0.598, 0.691, and 0.903 kg an^{-1} day^{-1} for red criollo, braham, and braham x holstein crosses, respectively. Similar results were found at 700 m altitude by Cowan et al. (1974), but in this case milking cows were grazed on guineagrass-glycine and kikuygrass (*Pennisetum clandestinum*) pastures without any supplementation. Milk production averaged 9.06 and 12.54 kg cow^{-1} day^{-1} for jersey and holstein cows, respectively. In Australia, Grof and Harding (1970) found that a guineagrass-centro pasture yielded 36% more liveweight than Guineagrass alone, over a two year period. Hall (1970) reported that animal production on unimproved native grass was less than 9 kg ha^{-1} when compared to guineagrass-Siratro mixture which yielded 112 kg liveweight ha^{-1}.

In Costa Rica, Kretschmer (1971) reported that centro in mixtures with guineagrass increased forage yield by 20% during the dry season and by 30% during the wet season, when compared with grass alone. Tergas (1976) reported that centro increased total forage production

by 40% when it was grown in mixtures with guineagrass, and the amount of N fixed by the legume was estimated to be 100 kg N ha^{-1} yr^{-1}. In northern Australia, Norman (1970) showed that gain per animal grazing legume-grass mixtures was linearly related to the proportion of legume in the pasture. Also, animal liveweight gain during the dry season was related to the number of days during which the animals had been grazing the legumes. He also reported that animals grazing on grass pastures gained 60 kg $head^{-1}$, while those allowed to graze grass-legume pastures gained 280 kg $head^{-1}$. During the period of 112 days of the dry season, the first group on grass pastures lost almost 40 kg $animal^{-1}$, while the second gained 60 kg $animal^{-1}$, due to the companion legume, Stylosanthes humilis. In Ecuador, Chavez (1974) reported that a guineagrass-centro mixture produced 536.5 kg liveweight gain ha^{-1} $year^{-1}$ with the beneficial effect of the legume being more apparent during the dry season, when crude protein content of the guineagrass alone was below 7% and crude protein content for the grass-legume pastures over 10%. Similar results were reported by INIAP (1979) on guineagrass-glycine var 'Tinaroo' mixture, which produced 458 kg of liveweight ha^{-1} $year^{-1}$. In both cases the results were obtained under rotational grazing using the put-and-take technique developed by Mott (1960).

According to Minson and Milford (1967), tropical legumes maintain adequate nutritive values for a longer period of time than most tropical grasses, when each were under the same management system. The critical level of crude protein required in a pasture before intake is reduced by protein deficiency is estimated to lie between 6.0 and 8.5%. Even highly N-fertilized tropical grasses at late growth stages may have

values below these points (Ventura et al., 1975). Tropical forage legumes, on the other hand, retain higher crude protein levels during the dry season, even in advanced maturity stages (Milford and Haydock, 1965). Selectivity by grazing animals is a possible explanation for higher performance of grazing cattle during the dry-season periods in tropical regions, especially when available forage meets or exceeds animal requirements (t'Mannetje, 1974).

Pasture Evaluation

Mott and Moore (1970) developed a five-phase scheme for forage evaluation. Such a scheme involves quantity and quality determinations.

Phase: I. Introduction and breeder's lines,

II. Small plot clipping trials,

III. Mob grazing experiments, forage response to grazing animals,

IV. Animal response, effect of forage on animal output,

V. Forage-livestock feeding systems.

Forage quality, _in vitro_ organic matter digestibility (IVOMD) is taken into consideration in the first three phases, while phases IV and V involve animal response in nutrient digestibility, performance per animal and production per hectare.

Definitions for stocking rate, grazing pressure, and carrying capacity were given by Mott (1960). Stocking rate is defined as the number of animals per unit area of land, the term bearing no relationship to the amount of forage. Grazing pressure is the amount of forage dry matter on offer per animal per day and carrying capacity, also called grazing capacity, is defined as the stocking rate at the

optimum grazing pressure. McMeekan (1956) considered the stocking rate as the most powerful factor, influencing the efficiency of pasture conversion to animal products on a per unit area basis. Petersen et al. (1965) developed quantitative expressions which related grazing pressure and carrying capacity with output per animal. Their quantitative theory suggests that animal gain is constant as the stocking rate is increased up to a "critical point," where the grazeable forage is equal to the amount of forage consumed by grazing animals. If the stocking rate is increased beyond the critical point, then the gain per animal decreases, and the animal gain per unit area also decreases. Conway (1965), using three stocking rates, 1.0, 1.75, and 2.5 animals per acre, found that by increasing the stocking rate from 1.0 to 1.75 animals per acre, liveweight gain per animal decreased. However, with 2.5 animals per acre, the liveweight per animal was drastically reduced resulting also in a reduction of liveweight per acre. Jones (1979) in Australia studied the effect of five stocking rates, namely 0.8, 1.3, 1.8, 2.3, and 2.8 an ha^{-1} in combination with three resting periods of 17, 39, and 50 days using a randomized complete block design with two replications. The area allocated to each treatment varied from 0.02 to 0.24 ha, using just one animal per experimental unit. Increasing the stocking rate had the greatest influence upon the persistence of the legume which in this case was Siratro. Also, the resting period became important to the legume productivity under heavy grazing pressure conditions. Results suggest that under heavy grazing pressure a longer rest period would allow the legume to increase or maintain its reserves of nutrients for subsequent growth. Echandi (1956) suggested that carrying capacity

should be determined taking into consideration the amount of litter left in the field as residue after each grazing period. Mott (1973) emphasized the use of variable stocking rates in grazing experiments by maintaining the number of animals in equilibrium with the available forage. He noted that the important advantage of the system was that it permits estimation of the carrying capacity of the pasture and the seasonal changes which occur. Evans and Bryan (1973) pointed out the need for more studies to evaluate different grazing pressures in order to measure the yield of the pasture and persistence of tropical legumes.

According to Mott (1973) the optimum grazing pressure must be considered as an optimum range instead of a "critical point" and that such an optimum relates only to animal output and may or may not be the optima for plant species in the pasture. Mott and Lucas (1952), Mott (1960), and Matches (1970) described the put-and-take technique for grazing trials. They suggest that the stocking rate must be variable in which the grazing pressure is maintained at a constant level and the stocking rate adjusted as the availability of forage changes. These authors also distinguish the terms "testers" for animals which should remain in the pasture throughout the grazing experiment and "grazer," or put-and-take animals, as those used to maintain the grazing pressure at the optimum. Mott pointed out that "if the number of animals per unit area is to give an accurate appraisal of carrying capacity, then this unit of measure must not be fixed but be subject to adjustment, so that the number of animals per unit of forage is maintained at an equivalent level for

all treatments" (1960, p. 601-602). Serrao (1976) suggested that variable or fixed stocking rates can be used in continuous or rotational grazing systems. He concludes that the put-and-take system is more appropriate when plant and animal relationships are to be measured.

Grazing Systems

Continuous Grazing

Heady (1970) noted there is much confusion in the definition of grazing systems which are used for describing the day to day provision of livestock feed from a wide variety of sources such as conserved forage and by direct use of pasture by grazing animals. He also defined continuous grazing as a grazing system in which the animals have unrestricted access to any part of the pasture through a grazing period, which can be a season, a year or more. Spedding (1965) suggested a pasture under a continuous grazing system could be called correctly grazed when the amount of removed forage by the grazing animals was equal to the amount of forage daily yield. Continuous grazing is the most commonly used system in the tropics, especially on vast areas, far away from the main consumer centers and in many cases areas without any suitable highway system (Chaverra, 1979).

Rotational Grazing

A rotational grazing system is defined by Heady (1970) and Heath (1978) as a system in which the animals are allowed to graze the pasture for variable periods of time, normally with a heavy stocking rate, during which the pasture is grazed and ungrazed several times during a grazing season or year.

The terms grazing period and rest period are commonly used in the rotational grazing system (Heady, 1970). According to Heady (1970) the grazing period is the portion of the grazing time during which grazing takes place and rest period is the time during which the pasture is not grazed. Comparing both continuous and rotational grazing systems on animal production, Stobbs (1969), in Africa, found that animal production was slightly higher for rotational grazing when it was carried out in three paddocks, but it was lower than continuous grazing when it was done in six paddocks. From Australia, Grof and Harding (1970) reported that a mixed Guineagrass-centro pasture with a carrying capacity of 3.5 an ha^{-1} produced a liveweight gain of 934 kg ha^{-1} for 2 years and 1075 kg ha^{-1} for 2 years for continuous and rotational grazing, respectively. From Pichilingue, Ecuador, Paredes (1974) reported that during the rainy season there were no differences in stocking rate between continuous and rotational grazing, but during the dry season continuous grazing under variable stocking rate was superior to rotational grazing with fixed or variable stocking rate. He also found that continuous grazing with variable stocking rates gave the highest average daily gain of 0.457 kg an^{-1} day^{-1}.

Estimates of Dry Matter Production and Yield

Estimation of production and yield are major problems in grazing experiments, because of the heterogeneity of the pasture sward and the amount of time required to obtain an adequate sample. One must decide the number of samples, the area to be sampled, and choose an adequate technique for sampling a highly variable population where cover, density,

height, weight, and other factors differ from one species to another (Kennedy, 1972). For many years, hand cutting and weighing of aboveground vegetative parts has been the most popular and useful method for estimating forage yield (Heady, 1970) and for estimating grazing pressure (Mott, 1960). Other methods, such as the simple disk meter, described by Bransby (1975), work on the principle of measuring the height of a disk supported by the resistance and compression of the vegetation. Santillan (1976) proved that the simple disk meter was very satisfactory for use in tropical species.

Mott (1974) suggested that estimation of total yield or yield of components is based upon the following relationship: yield per unit area = f (density, height). The total yield of an area of vegetation is related to the density and height of individual components. Ground cover and sward height have been used on different types of grassland to estimate dry matter yield.

Where pasture vegetation is utilized by grazing animals, the amount of feed present at any one time may be only one of the factors associated with the intake by the grazing animals. Of interest to the pasture scientist is an estimate of that portion of the pasture which is consumed by the grazing animal since they are very selective of plant species and plant parts, which makes for a more complex situation (t'Mannetje, 1978).

A double sampling technique is probably one of the best ways to ensure a more precise yield determination. Eye-estimation in combination with a few harvested samples which act as a control on the observer's accuracy is one of the simplest forms of estimating total forage present or annual production potential of a pasture (t'Mannetje, 1978).

Measuring Botanical Composition

Botanical composition is a very essential measurement, especially in pastures subjected to grazing conditions, because the number of samples and yield of individual species may vary over a wide range depending upon environmental conditions and management factors. T'Mannetje et al. (1976) indicated that botanical composition can be measured in terms of the yield of component species, the number of plants covering the area and also the frequency of occurrence.

Determination of botanical composition and sampling techniques are difficult tasks in pasture research. Some methods have been developed to determine botanical composition; the most common are visual estimation and hand separation of harvested material into component species (Gardner, 1972). Visual estimation is a reliable method for studying pasture species, but in some cases it may be difficult to relate dry matter production of each of the component species, especially when growth habit and density differ widely. Tothill and Petersen (1962) indicated that the weight *in situ*, as well as the estimation of weight of each individual species, and visual estimation are the most useful methods for surveying vegetation of pasture species.

Effect of the Grazing Animal on Botanical Composition

There are at least three factors that are known to affect the balance of the grass-legume mixtures in the tropics once the pasture has been established. They are stocking rate or grazing pressure, frequency of defoliation, and fertilization.

The grazing animal has a direct effect on pasture species due mainly to selectivity, deposition of feces and trampling, and an indirect effect on the soil due to the removal of nutrients by the removal of harvested forage. The animal alters the physical and chemical properties such as structure, texture, porosity, water retention, and in some cases, the accumulation of organic matter at certain points due to fecal deposits. All of these changes have a direct consequence, first on the botanical composition and subsequently on the final performance of that grazing animal (Alarcon and Lotero, 1970).

Research workers such as Davis (1967) and Wells (1967) agreed that grazing affects the soil cover and botanical composition which results in (1) a reduction of the basal cover, (2) a reduction of height of species, (3) a loss of soil cover and severe erosion, (4) a reduction of root systems, (5) a reduction in the emergence of new shoots, and (6) weed invasion.

Bryan and Evans (1973) found that the proportion of legumes *Stylosanthes guianensis*, *Centrosema pubescens*, and *Pueraria phaseoloides* on the dry matter basis was not affected by stocking rates during the first and second year. In the third year a marked reduction took place on the high stocking rate of 6 animals ha^{-1}, in which the proportion of the legumes fell from 22 to 12%, while the companion grass (Panicum maximum) was more affected by the high stocking rate. In this case the reduction was significant since it went from 78 to 65% and to 38% in the first, second and third year, respectively. The other two stocking rates of 2 and 4 animals ha^{-1} had little effect on

the grass and legume during the three experimental years. Similar results were reported from Africa by Stobbs (1969).

Cowan et al. (1975), in the Atherton Tableland, Queensland, Australia, found a highly significant correlation coefficient between milk yield ha^{-1} and the amount of the legume glycine present in the pasture. They studied four stocking rates, 1.3, 1.6, 1.9, and 2.5 cows ha^{-1}. On the other hand, while stocking rate was increased the milk production ha^{-1} also was increased but the percentage of dry matter of legume present in the pasture decreased when the stocking rate increased. Cowan and O'Grady (1976) reported the same trend under similar conditions in another study carried out later at the same location.

Some investigations carried out in Cuba have shown that under heavy stocking rates the legumes fail to persist in the mixture. Febles and Padilla (1972), using a stocking rate of 4 cows ha^{-1}, found that a mixture of guineagrass and the legumes glycine, Siratro, *Stylosanthes guianensis*, *Desmodium intortum*, and *Desmodium uncinatum*, did not persist more than 36 weeks. Funes and Perez (1976), using six animals ha^{-1}, also found that the three commercial cultivars of glycine (Tinaroo, Cooper, and Clarence) failed to persist under those conditions and that at 36 weeks the proportion of weedy species was drastically increased. Their final conclusion was that it is better to use light stocking rates and that the legumes are useful in those areas in which the grazing management is extensive. On the other hand, there are some results that show a positive effect of stocking rate upon the proportion of legume in the pasture. Vilela (1979), in Brazil, found that

the legume percentage was 8.7, 10.5, and 15.6 for the 0.5, 1.0, and 1.5 animals ha^{-1}, respectively, when it was measured with the point quadrat method.

Jensen and Schumacher (1970) observed that the percentage of botanical species is not only affected by grazing animals, but also by environmental conditions such as season, precipitation, rain distribution, temperature, and solar radiation. Taking into consideration most of the above factors, Tothill (1978) noted that if the primary objective of the investigation is to obtain an estimate of botanical composition of pastures in assessing animal production, weight of species is the most suitable value to measure. If rainfall interception or photosynthesis are under study, then cover may be the more appropriate parameter. He also mentioned that the importance of this distinction is that number, weight and cover measurements are comparable in time and space, but are independent of the mode of sampling since they are measured directly and expressed in relation to a unit area. Shaw and Bryan (1976) mentioned that the proportion of species on a weight basis is generally the most useful where the main interest is in pasture production and where samples are cut for yield determination, and botanical composition can be determined by hand-separating the sample into component species. They also added that this is the most precise and satisfactory method for yield and botanical composition determinations.

Response Surface Methodology

Littell and Mott (1975) indicated that the purpose of response surface methodology is to estimate the functional relationship between a response variable such as yield and an experimental variable or

control variables, such as rates of P. They also suggested that the range of values determines the experimental region, and the functional relationship is called the response surface.

Factorial arrangements of treatments provide good information, but they require greater numbers of experimental units and more physical resources; with the same amount of resources using response surface methodology, it is possible to obtain results from a much greater number of variables and levels within each variable. These designs, such as the rotatable central composite, non-rotatable central composite and San Cristobal, have been used in grazing trials and have proved their usefulness in obtaining valuable data (Maraschin, 1975; Mott, 1977; Serrao, 1976; Villasmil et al., 1975).

Maraschin (1975) and Serrao (1976), both using a central composite design, studied the effect of three variables: grazing days (1, 3.5, 7, 10.5, and 14), resting periods (0, 14, 28, 42, and 56 days), and dry matter residue left after grazing (500, 1000, 1500, 2000, and 2500 kg DM ha^{-1}) upon the botanical composition of _Cynodon dactylon_-_Desmodium intortum_-_Macroptilium atropurpureum_-_Lotononis bainesii_-_Trifolium repens_ mixture. The great advantage of this design is that it used only 24 treatments instead of 125 that the complete factorial would have required for a single replication, to obtain the coefficients needed to evaluate the grazing management systems. Serrao (1976) reported that the most important factors in determining dry matter yield from pasture and also legume percentage maintained in the mixture were grazing pressure and rest periods. He found that the legume content of the mixture was increased with an increase in length of rest period

and that heavy grazing pressure and short rest periods almost eliminated the legumes from the pasture.

CHAPTER III
MATERIALS AND METHODS

This research was conducted at Estacion Experimental Tropical Pichilingue, belonging to INIAP and located 7 km from Canton Quevedo, Procincia de los Rios, at 1° 06' S Lat. and 79° 29' W Long. Altitude at the site is 64 m above sea level. The average minimum and maximum temperatures are 17.3 and 35.6°C, respectively, having a mean annual temperature of 24.3°C. Annual precipitation is 2152 mm. About 82% of the yearly rainfall occurs during the warmer months from December through June. The months of February and March have the highest rainfall intensity. By contrast, October and November are the driest months, often registering no rainfall. Annual mean relative humidity is 84% and mean sunlight is 846.2 hours per year, 66% of which occurs during the December to May period (Servicio Nacional de Hidrologia y Meterologia del Ecuador, 1980). Holdridge (1967) located Pichilingue in the tropical moist forest zone (Fig. 1).

Figures 2, 3, and 4 present the monthly rainfall range, average temperature and average solar radiation for the years 1978, 1979, and 1980.

The soils are classified as Torripsamments. Hardy (1960) states that the chemical analysis of this Pichilingue loam reveals a marked deficiency in available P, but an abundance of available K. The soil N status is fair to medium in recently cleared land, but declines rapidly with cultivation. More recent soil analyses at the experimental site revealed that the amount of P is medium, while B, S, Zn and Mo are low (INIAP, 1979).

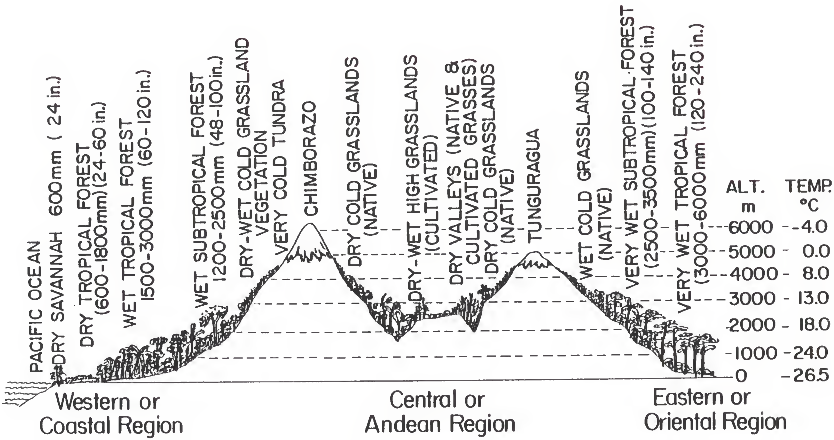

Fig. 1. Profile of the three natural regions of Ecuador, showing the main vegetative zones in relation to rainfall and temperature.

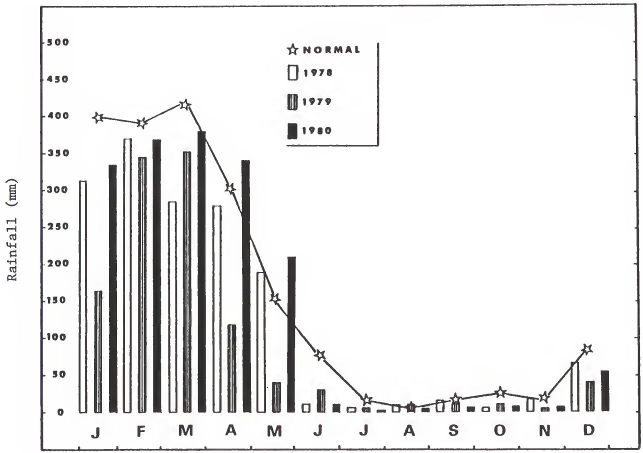

Fig. 2. Rainfall recorded at Estacion Experimental Pichilingue during the period of 1978–1980.

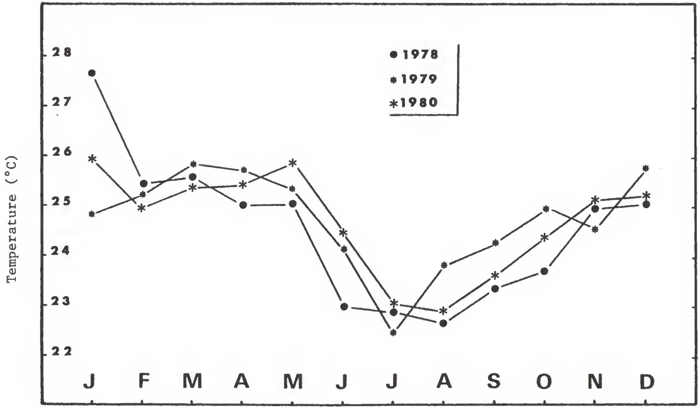

Fig. 3. Temperature recorded at Estacion Experimental Pichilingue during the period 1978-1980.

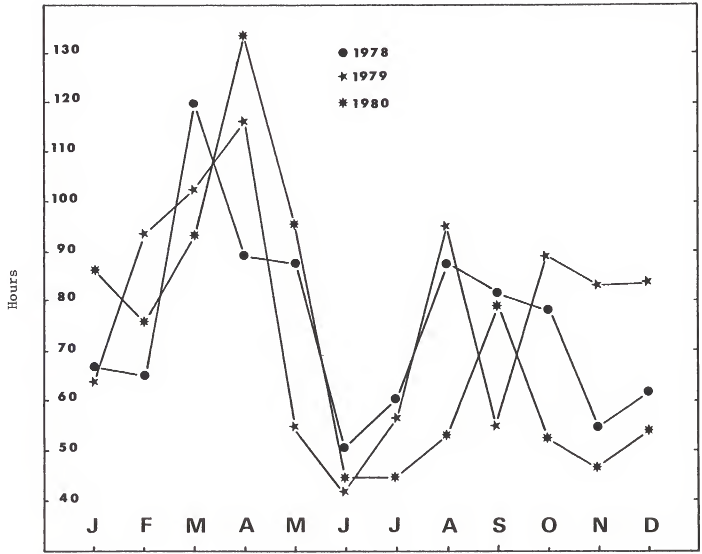

Fig. 4. Solar radiation at Estacion Experimental Pichilingue during the period of 1978-1980.

Table 1 presents the soil analysis on the experimental site used in this research.

Legume-Grass Mixture

The legume-grass mixture selected for the experiment consisted of Malawi glycine [*Neonotonia wightii* (R. Grah x Wightii and Arn.) Lackey], commercial centro (*Centrosema pubescens* Benth.), guineagrass (*Panicum maximum* Jacq.), and Hybrid 534 elephantgrass (*Pennisetum purpureum* Schumach.).

Guineagrass and elephantgrass were considered because both are very common and useful grass species in the littoral region of Ecuador, and also because of their high-yielding capacity, drought tolerance, and ability to grow in mixture with some tropical legumes. Centro is a native legume and may be the most widespread in the lowlands extending from dry tropical forest to wet tropical forest (600-2500 mm of rainfall). Glycine had been selected from previous experiments as a very persistent and productive legume.

Experimental Variables

The experimental variables were

(1) Days grazing (X_1)--1, 7, 14, 21, 28;

(2) Days rest (X_2)--0, 14, 28, 42, 56;

(3) Grazing pressure (X_3)--dry matter on offer per 100 kg body weight (BW); and

(4) Phosphorus (P_2O_5) levels (X_4).

Table 1. Soil analysis of experimental site (1978).

Depth of sample: 0-25 cm

pH: 6.30

Percent organic matter: 4.96

Element	ppm
Phosphorus	62.5
Potassium	598.8
Sulfur	18.4
Zinc	13.2
Manganese	258.5
Copper	20.9
Boron	12.6

For this experiment grazing pressure was expressed as the amount of dry matter on offer per 100 kg body weight (BW) and by the residual dry matter in kg ha^{-1} left after each grazing.

Each experimental variable was studied at five levels. Therefore, the treatments comprised a factorial type of experiment of four factors, each at five levels (5^4 factorial) (Table 2).

Experimental Design

Due to the large number of experimental units required to conduct a 5^4 factorial (626 treatment combinations without replications), a response surface design, namely, a modified central composite non-rotatable design was used. The number of design points (treatment combinations) was determined from the following formula: (see Table 2)

No. of design points = 2^4 (±1) + 2^4 (±2) + (2 x 4) + 1 = 41

Certain treatments were replicated twice (central point was replicated thrice) and these are indicated in Table 2. The total number of experimental units was 51.

Field Plan of the Experiment

In order to estimate the size of experimental units for each treatment, the following formula was used: (see Table 3)

$$S = \frac{NdR}{DG}$$

where S = size of experimental unit in m^2,

N = kg body weight/pasture/day (assumed 300 kg BW),

d = number of days pasture is grazed during cycle,

Table 2. Modified central composite non-rotatable design with four experimental (X) variables, at five levels each, and 41 design points.

	Treatments									
	Coded				Days Grazing	Days Rest	Grazing Pressure	Fertilizer Level		
No.	X_1	X_2	X_3	X_4	(X_1)	(X_2)	(X_3) % BW $\underline{R}$	(X_4) kg ha^{-1}	Reps	Days in cycle
1	-1	-1	-1	-1	7	14	3.3	100	1	21
2	1	-1	-1	-1	21	14	3.3	100	1	35
3	-1	1	-1	-1	7	42	3.3	100	1	49
4	1	1	-1	-1	21	42	3.3	100	1	63
5	-1	-1	1	-1	7	14	6.6	100	1	21
6	1	-1	1	-1	21	14	6.6	100	1	35
7	-1	1	1	-1	7	42	6.6	100	1	49
8	1	1	1	-1	21	42	6.6	100	1	63
9	-1	-1	-1	1	7	14	3.3	300	1	21
10	1	-1	-1	1	21	14	3.3	300	1	35
11	-1	1	-1	1	7	42	3.3	300	1	49
12	1	1	-1	1	21	42	3.3	300	1	63
13	-1	-1	1	1	7	14	6.6	300	1	21
14	1	-1	1	1	21	14	6.6	300	1	35
15	-1	1	1	1	7	42	6.6	300	1	49
16	1	1	1	1	21	42	6.6	300	1	63
17	-2	-2	-2	-2	1	0	1.6	0	1	Cont
18	2	-2	-2	-2	28	0	1.6	0	1	Cont
19	-2	2	-2	-2	1	56	1.6	0	2	56
20	2	2	-2	-2	28	56	1.6	0	2	84
21	-2	-2	2	-2	1	0	8.3	0	1	Cont
22	2	-2	2	-2	28	0	8.3	0	1	Cont
23	-2	2	2	-2	1	56	8.3	0	2	56
24	2	2	2	-2	28	56	8.3	0	2	84

Table 2.--continued.

No.	Coded				Treatments				Reps	Days in cycle
	X_1	X_2	X_3	X_4	Days Grazing (X_1)	Days Rest (X_2)	Grazing Pressure (X_3) % BW R	Fertilizer Level (X_4) kg ha^{-1}		
25	-2	-2	-2	2	1	0	1.6	400	1	Cont
26	2	-2	-2	2	28	0	1.6	400	1	Cont
27	-2	2	-2	2	1	56	1.6	400	2	56
28	2	2	-2	2	28	56	1.6	400	2	84
29	-2	-2	2	2	1	0	8.3	400	1	Cont
30	2	-2	2	2	28	0	8.3	400	1	Cont
31	-2	2	2	2	1	56	8.3	400	2	56
32	2	2	2	2	28	56	8.3	400	2	84
33	-2	0	0	0	1	28	5.0	200	1	28
34	2	0	0	0	28	28	5.0	200	1	56
35	0	-2	0	0	14	0	5.0	200	1	Cont
36	0	2	0	0	14	56	5.0	200	1	70
37	0	0	-2	0	14	28	1.6	200	1	56
38	0	0	2	0	14	28	8.3	200	1	56
39	0	0	0	-2	14	28	5.0	0	1	56
40	0	0	0	2	14	28	5.0	400	1	56
41	0	0	0	0	14	28	5.0	200	3	56

Table 3. Modified central composite non-rotatable design with four experimental (X) variables, at five levels each, 41 design points, 51 experimental units with their respective area.

No.	Pasture No.	Treatments: Days Grazing (X_1)	Days Rest (X_2)	Grazing Pressure (X_3) % BW	Fertilizer Level (X_4) kg ha^{-1}	Reps	Size of Exp. Unit M^2 S	Total† Area Required per Treat.
1	18	7	14	3.3	100	1	750	750
2	28	21	14	3.3	100	1	1500	1500
3	44	7	42	3.3	100	1	500	500
4	23	21	42	3.3	100	1	750	750
5	20	7	14	6.6	100	1	1500	1500
6	50	21	14	6.6	100	1	2000	2000
7	24	7	42	6.6	100	1	1000	1000
8	33	21	42	6.6	100	1	1500	1500
9	8	7	14	3.3	300	1	750	750
10	30	21	14	3.3	300	1	1500	1500
11	4	7	42	3.3	300	1	500	500
12	37	21	42	3.3	300	1	750	750
13	16	7	14	6.6	300	1	1500	1500
14	43	21	14	6.6	300	1	2000	2000
15	26	7	42	6.6	300	1	1000	1000
16	15	21	42	6.6	300	1	1500	1500
17	34	1	0	1.6	0	1	2000	2000
18	31	28	0	1.6	0	1	2000	2000
19	25,36	1	56	1.6	0	2	500	500
20	6,13	28	56	1.6	0	2	750	750
21	35	1	0	8.3	0	1	4000	4000
22	22	28	0	8.3	0	1	4000	4000
23	32,45	1	56	8.3	0	2	500	1000
24	27,48	28	56	8.3	0	2	2000	2000

Table 3.--continued.

No.	Pasture No.	Treatments: Days Grazing (X_1)	Days Rest (X_2)	Grazing Pressure (X_3) % BW	Fertilizer Level (X_4) kg ha^{-1}	Reps	Size of Exp. Unit M^2 S	Total† Area Required per Treat.
25	10	1	0	1.6	400	1	2000	2000
26	29	28	0	1.6	400	1	2000	2000
27	12,47	1	56	1.6	400	2	500	500
28	7,40	28	56	1.6	400	2	750	750
29	14	1	0	8.3	400	1	4000	4000
30	49	28	0	8.3	400	1	4000	4000
31	28,46	1	56	8.3	400	2	500	1000
32	3,21	28	56	8.3	400	2	2000	2000
33	5	1	28	5.0	200	1	500	500
34	51	28	28	5.0	200	1	2000	2000
35	42	14	0	5.0	200	1	3000	3000
36	17	14	56	5.0	200	1	750	750
37	11	14	28	1.6	200	1	750	750
38	2	14	28	8.3	200	1	1500	1500
39	1	14	28	5.0	0	1	750	750
40	9	14	28	5.0	400	1	750	750
41	19,39,41	14	28	5.0	200	3	750	2250

†Total area = 73000 m2.

R = kg dry matter offered/kg body weight/day,

D = number of days in cycle, and

G = growth rate in kg/m^2/day (assumed .04 kg/m^2/day).

As an example, treatment 14 days of grazing, 28 days of rest, and 5.0 kg DM on offer/100 kg BW/day is calculated as follows:

$$S = \frac{300 \times 14 \times .05}{42 \times 0.004} = 1250 \text{ m}^2$$

This figure was rounded to 1500 m^2 to avoid the inconvenience of odd pasture sizes. All pastures were 500 m^2 or some multiple (Table 3). In making this calculation it was assumed that one animal weighing approximately 300 kg was used to graze the pasture during the allotted grazing period and designated grazing pressure. It was also assumed that the growth rate was 4 g/m^2/day. In estimating the size (S) of the experimental unit the smallest was set at 500 m^2 in order to avoid difficulty in handling the steers in units of smaller size. A total of 7.3 hectares were required for the 51 experimental units in this study (Table 3). These pastures were randomly distributed as shown in Fig. 5. The sizes of the experimental pastures varied from 500 m^2 to 4000 m^2; the larger areas were for the continuously grazed treatments (Fig. 5).

Land Preparation and Pasture Establishment

Land preparation of the experimental area began in May 1977, after the existing vegetation (common guineagrass) was partially eliminated by an application of a grass killer herbicide (Glyfosate®). At the beginning of July the 6-year-old guineagrass pasture was plowed under.

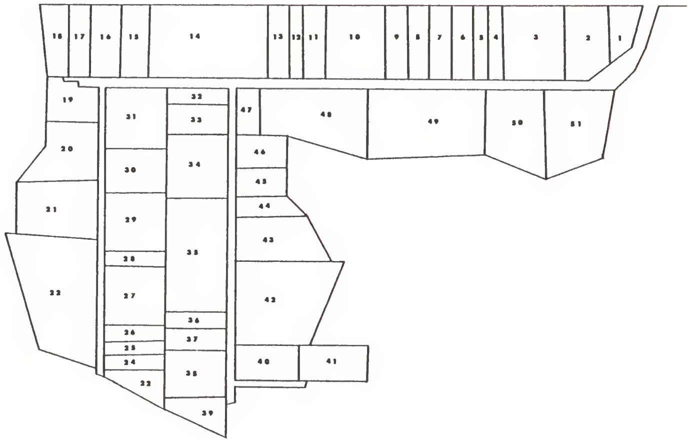

Fig. 5. Field plan of the experimental pastures.

In August the complete area was cross-disced in order to eliminate some weeds and obtain a good seedbed. The area was disced again in late September to eliminate the new growth and some weeds. In the same month, 20 small soil samples were taken from the whole area and mixed together for soil analysis; the samples were taken at 25 cm depth (see Table 1).

The next step was to prepare the legume seeds. Glycine and centro seeds were scarified using sulfuric acid for a time of 6 and 8 minutes, respectively. After the seeds were washed and shade dried, they were inoculated using an appropriate Rhizobium strain obtained from CIAT (Centro Internacional de Agricultura Tropical). In early October of 1977, a mixture of glycine and centro was sown using a small grain seeder with a four row capacity at the rates of 3.0 and 6.0 kg ha^{-1}, respectively. The mixture was sown in rows spaced 1.4 m apart. A day after the sowing, a mixture of preemergence herbicides was applied (Linuron® 0.75 kg ha^{-1} + 2 L ha^{-1} of Laso®) to control both grasses and broadleaf weeds coming from seed. Two weeks after the legumes were sown, the grasses were planted vegetatively, using plant divisions for guineagrass and small pieces of stems with two or three buds for elephantgrass. Both grasses were planted alternatively between the rows of the legumes, so that the distance between grasses and legumes was 0.70 m. It was necessary to make one hand weeding using machetes. Four irrigations of 4 mm each were necessary at 12 day intervals. The first irrigation was immediately after the legumes were sown.

In early January of 1978, the P fertilizer was applied taking into consideration the respective levels of simple superphosphate kg ha^{-1} (whose composition was 18.2% P_2O_5 and 14% elemental S); at the same time a mixture of micronutrients was applied to the whole area. The composition of this mixture was 3 kg Zn chelate, 4 kg Fe chelate, 3 kg $CuSO_4$, 3 kg Borax, and 0.8 kg Molybdenum nitrate ha^{-1}.

Construction of Physical Facilities

In February, the total area was surveyed for the purpose of locating the fence lines, and four-strand wire fences were built. During the second half of March, the entire area was moderately grazed and the remaining vegetation was mowed at 15 cm height. Wooden mineral boxes were built which were used to supply the following formula: 50% of sodium chloride + 50% of mineralized salt containing 7% P as dicalcium phosphate, 0.48% Zinc sulfate, 0.12% manganese carbonate, 0.14% copper sulfate, 0.32% ferrous sulfate, and 0.006% cobalt chloride. Water tanks were provided in each experimental pasture. An area of approximately 10 ha adjacent to the experiment was available as reserve pasture for 50 animals used for adjusting the stocking rates in the experiment.

Collection of Data in the Three Experimental Years

On May 12, 1978, experimental grazing was initiated. Fifty-six Criollo and Holstein/Brahman steers were used to graze the experimental pastures. At the start of the experimental period, the

animals were 16 months old and their average weight was 268 kg. Every 28 days all animals were removed from the pastures and from the reserve pasture. They were taken to the main corral for tick treatments and every 56 days they were weighed in order to have a basis for estimating stocking rates for the next grazing cycle.

At the end of the first experimental year, the pool of animals was removed from all the pastures and showed average weights of 428 kg. A new pool of younger animals replaced the first group for the second year, having an average weight of 302 kg. The animals for the second experimental year were from the same herds as those of the first year and were 18 months old.

Pasture Measurements

Dry Matter Determination Before and After Grazing

Dry matter ha^{-1} estimates before (on offer) and after (residual) each grazing period were made in order to apply the required grazing pressure and to determine the net dry matter production.

Stocking rate was determined for grazing pressure-grazing period combination on the basis of the total dry matter available before each grazing plus the estimated growth rate during the grazing period. Growth rate during the grazing period was assumed to be the same as that of the previous rest period. The accuracy of this technique for determining stocking rate was checked, using the residual dry matter left on the field after each grazing period. Grazing pressure was also based on visual observations of the amount of dry matter during each grazing period, in order to add or remove animals from pastures

depending on the specified dry matter on offer and days of grazing. In order to estimate the grazing pressure, the following formula was used:

$$G/P = \frac{(A - r + gd)\,S}{RNd}$$

where G/P = grazing pressure in terms of 100 kg BW,

A = available forage before grazing,

r = residue for a specified grazing pressure,

g = growth rate-preceding rest period,

d = number of days for grazing period,

S = size of the experimental unit in m^2,

R = kg dry matter offered/kg body weight/day, and

N = kg body weight/pasture/day.

A double sampling technique was employed. As soon as possible, before and after each grazing (during the first 3 1/2 months only), 15 areas measuring 1.0 m^2 were randomly selected. From September 30, area measurements of the same size were taken, corresponding to the circular frame of a forage disk meter (one m^2) similar to the one described by Bransby (1975) and used in double-sampling measurements. In each sampling unit the percent dry matter yield of each component of the mixture was visually estimated, followed by an estimate of the dry matter yield *in situ*. The disk meter was lowered on the forage and after a settling time of approximately 5 to 10 seconds, the disk height (in centimeters) was read off a graduated scale mounted on the center shaft of the disk meter and recorded.

During the first three and one-half months, from the 15 sampling units, three were randomly selected and clipped at ground level for

dry matter yield and botanical composition. In September, five sampling units out of 30 disk readings were randomly selected and clipped for the above determinations. These samples were later hand separated into their components, placed inside cloth bags properly identified and dried for 20 hours at 72°C. The sum of the dry weights of the components yielded the total dry weight of the sample. Sickles were used for harvesting the forage samples. The clipped samples were used to adjust through regression analysis the 15 or 30 disk-meter readings of dry matter yield. The forage meter readings and visual estimates of dry weight were used as independent variables in regression equations to generate the regression coefficients needed for calibration of the disk meter and for adjustment of the visual sample estimation. The visual estimate of percent yield was made for the component grasses (guineagrass and elephantgrass), legumes (centro and glycine), and weeds. Although the above grasses and others such as *Paspalum fasciculatum*, *P. paniculatum* and *Eleusine indica* were present in scattered, small patches in some pastures, they were included in the weed components. Likewise, some native *Desmodiums* were accounted for in the legume component.

The response of the pasture mixture to the experimental variables was measured in terms of the following parameters:

(1) Aerial biomass (DM) kg ha^{-1} = grass (DM) + legume (DM) + weeds (DM),

(2) Available forage (DM) kg ha^{-1} = grass (DM) + legume (DM),

(3) Grass yield (DM),

(4) Legume yield (DM),

(5) Yield of weeds (DM),

(6) Grass percentage, and

(7) Legume percentage.

The above parameters were statistically analyzed for the partial wet season (May-June) of 1978, the dry season of 1978, wet and dry seasons of 1979, and wet season of 1980. The data were processed using the programs RSREG for response surface design, and 63D for plotting the three-dimensional graphs of the Statistical Analysis System of the Northeast Regional Data Center of the University of Florida.

CHAPTER IV
RESULTS AND DISCUSSION

Only two of the four experimental variables included in this experiment, namely, lengths of rest period and levels of grazing pressure are discussed in this section. The other two variables, days grazing and fertilizer level had negligible effects upon the response of the pasture sward. Each of the response variables will be discussed in a separate section beginning in the wet season of 1978 and ending in the wet season of 1980.

Effect of Lengths of Rest Periods and Levels of Grazing Pressure on Aerial Biomass (DM)

The effect of the lengths of rest period and levels of grazing pressure on the aerial biomass is presented for each of the five seasons in Table 4. The total biomass is the average amount of dry matter present before each grazing period for the rotational grazing treatment combinations and for each grazing period of 56 days for continuous grazing.

Biomass Production (DM) for the Wet Season of 1978

During the first wet season only lengths of rest periods indicated an effect ($P < 0.01$) on the aerial biomass produced (Appendix Table 11). The linear components of the model accounted for 20% of the total variation, while the quadratic effects and interactions represented only 4 and 13% of the total variation, respectively (Appendix Table 11).

Table 4. Aerial biomass production (DM) by year, season, and treatment.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						kg ha^{-1}				
1	7	14	3.3	100	1	1790	2410	3090	2870	2470
2	21	14	3.3	100	1	1960	2730	3210	2530	3360
3	7	42	3.3	100	1	2630	2760	3850	2650	3140
4	21	42	3.3	100	1	1890	2530	3490	1860	3940
5	7	14	6.6	100	1	2360	3690	4830	4460	4500
6	21	14	6.6	100	1	2170	3050	3120	2880	2760
7	7	42	6.6	100	1	2710	4020	4240	3050	3980
8	21	42	6.6	100	1	1940	4640	5830	4720	5770
9	7	14	3.3	100	1	3150	1910	3320	2530	2970
10	21	14	3.3	300	1	2850	2920	4440	3230	4020
11	7	42	3.3	300	1	2300	2880	3610	2710	3830
12	21	42	3.3	300	1	1590	2230	4430	2500	5740
13	7	14	6.6	300	1	2290	2620	2850	3010	2550
14	21	14	6.6	300	1	3150	2940	2690	2310	2410
15	7	42	6.6	300	1	1870	4400	6130	5980	7240
16	21	42	6.6	300	1	3050	3100	3740	2780	3680
17	1	0	1.6	0	1	1750	1240	1210	1480	1920
18	28	0	1.6	0	1	1990	1120	1760	1270	1460
19	1	56	1.6	0	2	3750	3620	5760	3670	7510
20	28	56	1.6	0	2	2430	2260	4060	2790	3820
21	1	0	8.3	0	1	2280	3540	3940	4090	6270
22	28	0	8.3	0	1	1800	3580	3910	3960	4870
23	1	56	8.3	0	2	3380	4800	6630	3850	5450
24	28	56	8.3	0	2	3460	5750	5940	4450	6620

Table 4.--continued.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						kg ha^{-1}				
25	1	0	1.6	400	1	2030	1220	1390	2130	3010
26	28	0	1.6	400	1	1900	790	1220	1090	2820
27	1	56	1.6	400	2	2350	2450	4280	2150	3550
28	28	56	1.6	400	2	2700	2630	4090	2560	4030
29	1	0	8.3	400	1	1690	2620	3160	2650	3680
30	28	0	8.3	400	1	2440	2520	3600	3150	4160
31	1	56	8.3	400	2	2470	4870	6870	3690	7540
32	28	56	8.3	400	2	3730	4880	6350	5830	6160
33	1	28	5.0	200	1	2570	2710	3090	2780	2960
34	28	28	5.0	200	1	1570	2470	3490	2900	3420
35	14	0	5.0	200	1	2690	1720	1820	1650	1830
36	14	56	5.0	200	1	3130	3760	4450	3320	4030
37	14	28	1.6	200	1	1840	1910	2180	3360	2190
38	14	28	8.3	200	1	2530	2900	3660	3210	3560
39	14	28	5.0	0	1	1860	2550	3230	2730	3190
40	14	28	5.0	400	1	1960	2110	2420	2810	2560
41	14	28	5.0	200	3	2360	2370	3000	2420	2900

†D/G = days grazing, D/R = days rest, G/P = grazing pressure as % body weight, F = fertilizer.
‡W/S = wet season, D/S = dry season.

The biomass production varied from 1570 kg DM ha^{-1} for treatment 17 (1 day grazing, 0 days rest, 1.6 kg DM on offer/100 kg BW, and 0 kg ha^{-1} superphosphate) to 3750 kg DM ha^{-1} for treatment 19 (1 day grazing, 56 days rest, 1.6 kg DM on offer/100 kg BW, and 0 kg ha^{-1} superphosphate).

The aerial biomass production response to lengths of rest periods can only be explained by the management imposed during the first grazing season. All of the experimental pastures were grazed at a medium grazing pressure for 15 days during the latter part of March of 1978, after which they were mowed at about 15 cm above ground level. The wet season of 1978 was represented by a growth period of about 3 months from the first of April until June 30 when the wet season ended. The production data were obtained during this 3 month period beginning on May 12 after only about a month of regrowth. The pastures with short rest periods were included in the first sampling date and for some of these pastures the length of the grazing cycle was only 21 days which means that they had the opportunity to be sampled twice between May 12 and June 30. Pastures with a longer rest period accumulated more dry matter during the growth periods and, thus, showed a higher amount of dry matter produced. The analysis of variance for the wet season of 1978 is presented in Appendix Table 11.

Biomass Production (DM) for the Dry Season of 1978

The biomass production during the dry season of 1978 is also presented in Table 4. The biomass production varied from 790 to 4880 kg DM ha^{-1}, corresponding to treatments 26 (28 days grazing,

0 days rest period, 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate) and 32, respectively (28 days grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 400 kg of simple superphosphate). In general, the lowest values of biomass production corresponded to treatment combinations of short rest periods and high levels of grazing pressure, while the highest levels of biomass production corresponded to the treatment combinations with long rest periods and low levels of grazing pressure.

The linear components of the model accounted for 74% of the total variation, while the quadratic effects and interactions represented only 1 and 2%, respectively (Appendix Table 12). The experimental variables, length of rest period (X_2) and level of grazing pressure (X_3) each showed a linear effect upon biomass production ($P < 0.01$). There was a suggestion that levels of superphosphate (X_4) might be having some effect ($P < 0.10$) but the effects of days grazing (X_1) was nil. In all cases individual quadratic effects or interactions were not significant. The lack of interactions between X_2 and X_3 indicated that both variables were behaving independently. The biomass production was increased as the lengths of the rest period were increased and as grazing pressure was reduced. The analysis of variance for the dry season of 1978 is presented in Appendix Table 12.

Biomass Production (DM) for the Wet Season of 1979

The biomass production during the wet season of 1979 for each treatment combination is given in Table 4. Biomass production varied

from 1210 to 6630 kg DM ha^{-1}, corresponding to the treatments 17 [1 day grazing, 0 rest period (continuous grazing), 1.6 kg DM on offer/loo kg BW, and 0 kg ha^{-1} of superphosphate] and 31, respectively (1 day grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate).

During the wet season of 1979 both length of rest period and level of grazing pressure had an effect upon biomass production ($P < 0.01$), while no quadratic effects and interactions were noted. The linear components of the model accounted for 67% of the total variation, and only 2 and 1% of the total variation was represented by the quadratic and interactions. As is evident, the biomass production is increased as the length of the rest period is increased. The higher grazing pressures also decrease the biomass production and the greatest biomass production was reached when a long rest period and low grazing pressure were imposed. The analysis of variance for the wet season of 1979 is presented in Appendix Table 13.

Biomass Production (DM) for the Dry Season of 1979

Biomass production during the dry season of 1979 for each treatment combination is presented in Table 4. Biomass production varied from 1090 to 5980 kg DM ha^{-1}, corresponding to treatments 26 [28 days grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate] and 32 (28 days grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate). Again, the lowest values of biomass on offer ha^{-1} corresponded to treatment combinations of short rest periods or continuous grazing

with the highest grazing pressure, but both experimental variables acted independently from each other.

The linear components of the model accounted for 45% of the total variation, while the quadratic effects and interactions represented only 1 and 6% of the total variation, respectively (Appendix Table 14).

An examination of the individual linear effects showed that only the experimental variables, days rest (X_2) and grazing pressure (X_3) were affecting biomass production ($P < 0.01$). The number of days grazing (X_1) and fertilizer (X_4) had no effect upon biomass production. For each 14 days increase in the number of days rest there was a biomass production increase of 230 kg (DM) ha^{-1}, while for each unit (1.6 kg DM) decrease in level of grazing pressure there was an increase of 480 kg ha^{-1} in biomass production. The analysis of variance for the dry season of 1979 is presented in Appendix Table 14.

Biomass Production (DM) for the Wet Season of 1980

The lengths of rest period and levels of grazing pressure had a direct effect upon biomass production for the wet season of 1980 (Table 4). There was no interaction between these two experimental variables during this wet season.

The linear components of the model accounted for 43% of the total variation, while the quadratic effects and interactions represented only 8 and 1% of the total variation, respectively (Appendix Table 15). The total biomass production varied from 1460 to 7540 kg DM ha^{-1} for treatments 18 [28 days grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate] and 31

(1 day grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate). During this particular season, the amount of biomass production was again most affected by the length of rest period and by the levels of grazing pressure. The highest values of biomass production corresponded to the treatment combinations of long rest periods and low grazing pressures. For each 14 days increase in rest period, there was an increase of 550 kg DM ha^{-1} of biomass production, while for each unit (1.6 kg DM) decrease in grazing pressure there was a 450 unit increase in biomass production. The analysis of variance for the wet season of 1980 is presented in Appendix Table 15.

Summary of Biomass Production (DM)

In comparison of aerial biomass production (DM) among seasons and years, large differences, especially between wet and dry seasons, are observed. The principal environmental factors involved in these differences between seasons are precipitation, temperature, and solar radiation (see Fig. 2 of Materials and Methods). Every year the rainy season begins in the second half of December, initially with light showers and then increasing in amount and intensity reaching the highest peak of precipitation in February or March. After this time the amount and duration of the showers decreases until it reaches almost zero during the second half of June. About 90% of the total precipitation falls from December to June with the remaining months almost completely dry. The second important factor is temperature which is always higher during the rainy season reaching an average of 26°C during the wet season, while the average during the dry season

is 22° C. The third important factor is solar radiation which is also higher during the rainy season, reaching values of 500-600 hours of sunlight while from July to November this value averages 350-400 hours of sunlight. These three factors acting together are the main determinants of total aerial biomass production.

Another very important factor which must be taken into consideration is nitrogen. This element, at the beginning of the wet season, is rapibly mobilized from the soil organic matter, which has accumulated in the soil during the dry season. Sanchez (1977) has indicated that N in the tropics is rapidly utilized by actively growing plants with the occurrence of the first rains at the beginning of the wet season but that the remaining N is slowly released during the rest of the season. These three environmental factors plus the availability of N have a great impact upon the aerial biomass production.

The most important experimental variables influencing the aerial biomass production were days of rest (X_2) and grazing pressure (X_3). Each variable behaved independently and there was a direct relationship between the number of days rest which permitted the plants a better opportunity to accumulate reserves for more rapid regrowth and development after each grazing period.

A similar trend was also found for grazing pressure which was directly related to the amount of forage removed by the grazing animals which in turn was related to the high removal and damage to the growing points and axillary buds. Grazing pressure was related to the rate of recovery and subsequently the final production. Hodgson and Ollerenshaw (1969) mentioned that if grazing pressure is increased while resting

periods are decreased, the frequency and severity of defoliation is increased affecting directly the subsequent regrowth and the total dry matter yields. Harris (1978) reported that although the function of reserves, availability of growing points, and uptake characteristics are influenced by the level of stubble biomass, the relationship between stubble biomass and growth rate relates to the amount of photosynthetic tissues.

Effect of Lengths of Rest Period and Levels of Grazing Pressure Upon Available Forage (DM)

Available forage in this context represents the sum of the grass and legume component but is exclusive of the weeds.

The effect of the lengths of the rest period and grazing pressure upon available forage is presented in Table 5 for the five seasons of this experiment. The available forage is the average of the estimated amount of dry matter present before each grazing for the rotational grazing treatment combinations and for 56 days for the continuous treatment.

Available Forage for the Wet Season of 1978

During the first wet season, only the length of the rest period had an effect on available forage ($P < 0.01$). The linear components of the model accounted for only 20% of the total variation, while the quadratic effects and interactions represented 5 and 12%, respectively (Appendix Table 16).

The means of total available forage varied from 1420 kg DM ha^{-1} to 3720 kg DM ha^{-1} (Table 5) for treatments 34 (28 days grazing, 28 days

Table 5. Available forage (DM) by year, season, and treatment combination.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						kg ha^{-1}				
1	7	14	3.3	100	1	1640	2270	2230	2080	1550
2	21	14	3.3	100	1	1950	2720	3120	2380	3150
3	7	42	3.3	100	1	2590	2760	3850	2650	3140
4	21	42	3.3	100	1	1830	2510	3360	1800	3920
5	7	14	6.6	100	1	2330	3600	4660	4210	4070
6	21	14	6.6	100	1	2130	2990	3070	2870	2750
7	7	42	6.6	100	1	2620	4020	4240	3050	3970
8	21	42	6.6	100	1	1910	4640	5810	4720	5720
9	7	14	3.3	300	1	3150	1860	3100	2430	2540
10	21	14	3.3	300	1	2730	2810	4230	3030	3540
11	7	42	3.3	300	1	2300	2820	3610	2710	2830
12	21	42	3.3	300	1	1520	2230	4440	2470	5940
13	7	14	6.6	300	1	2290	2620	2840	3000	2520
14	21	14	6.6	300	1	2960	2870	2600	2260	2320
15	7	42	6.6	300	1	1790	4370	6130	5980	7230
16	21	42	6.6	300	1	3030	3000	3680	2720	3680
17	1	0	1.6	0	1	1650	1200	830	690	650
18	28	0	1.6	0	1	1990	1070	1380	760	560
19	1	56	1.6	0	2	3720	3600	5750	3670	7510
20	28	56	1.6	0	2	2390	2260	4040	2760	3820
21	1	0	8.3	0	1	2280	3500	3930	4640	6120
22	28	0	8.3	0	1	1800	3530	3810	3940	4840
23	1	56	8.3	0	2	3380	4790	6620	3820	5450
24	28	56	8.3	0	2	3400	5700	5900	4440	6620

Table 5.--continued.

No.	Treatments D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	1978 W/S‡	1978 D/S‡	1979 W/S‡	1979 D/S‡	1980 W/S‡
						kg ha^{-1}				
25	1	0	1.6	400	1	1990	1130	950	400	410
26	28	0	1.6	400	1	1810	790	990	840	340
27	1	56	1.6	400	2	2320	2450	4260	2080	3360
28	28	56	1.6	400	2	2700	2630	4090	2560	4030
29	1	0	8.3	400	1	1690	2610	3140	3620	5530
30	28	0	8.3	400	1	2350	2420	3530	3110	4040
31	1	56	8.3	400	2	2410	4840	6870	3660	7510
32	28	56	8.3	400	2	2540	4880	6330	5830	6160
33	1	28	5.0	200	1	2460	2660	3070	2760	2890
34	28	28	5.0	200	1	1420	2280	3160	2650	3220
35	14	0	5.0	200	1	2640	1700	1790	1650	1820
36	14	56	5.0	200	1	3130	3710	4410	1300	4030
37	14	28	1.6	200	1	1760	1850	1970	1860	1360
38	14	28	8.3	200	1	2460	2730	3550	3170	3470
39	14	28	5.0	0	1	2860	2550	3130	2720	3150
40	14	28	5.0	400	1	1920	2070	3390	2800	2500
41	14	28	5.0	200	3	2290	2340	2950	2380	2800

†D/G = days grazing, D/R = days rest, G/P = grazing pressure, and F = fertilizer.
‡W/S = wet season, D/S = dry season.

rest, 5.0 kg DM on offer/100 kg BW, and 200 kg ha^{-1} of superphosphate) and 19 (1 day grazing, 56 days rest, 1.6 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate), respectively.

Considering the individual linear effects, days rest (X_2) was the only experimental variable affecting available forage ($P < 0.01$). The other three experimental variables did not affect the available forage. Individual quadratic effects or interactions were not significant. The lack of interaction indicates days rest is acting independently over available forage, which means that the amount of available forage increases as the length of the rest period increases.

For each 14 days of increase in days rest (X_2), there was 190 kg ha^{-1} increase in the available forage.

Available Forage for the Dry Season of 1978 (DM)

Available forage varied from 790 kg DM ha^{-1} to 4880 kg DM ha^{-1}, corresponding to treatment combinations 26 [28 days grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate] and 32 (28 days grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate), respectively. During the first dry season, the lowest values of available forage were found in those treatment combinations of short rest periods or continuous grazing with the highest grazing pressure, while the highest values were the longest rest periods and the lowest grazing pressures.

The linear components of the model accounted for 74% of the total variation, while the quadratic effects and interactions represented only 1 and 1% of the total variation, respectively (Appendix Table 17).

An examination of the individual linear effects reveals that only the experimental variables days rest (X_2) and grazing pressure (X_3) had any effect upon available forage ($P < 0.01$).

The length of rest period increased the available forage as was also the case with a decrease in grazing pressure. For each increase of 14 days in the rest period there was an increase of 440 kg ha^{-1} of available forage and for each unit (1.6 kg DM) decrease in grazing pressure there was a 500 kg ha^{-1} increase in available forage. The analysis of variance for the dry season of 1978 is presented in Appendix Table 17.

Available Forage for the Wet Season of 1979 (DM)

During the wet season of 1979 the available forage (DM) varied from 830 kg DM ha^{-1} to 6630 kg DM ha^{-1}, corresponding to the treatment combinations 17 [1 day grazing, o days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate] and 23 (1 day grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate), respectively. The treatment combinations with the shortest rest periods and lowest grazing pressure levels yielded the lowest values of available forage for this season; also it was noted that in this case both variables X_2 and X_3 were acting independently. There was no evidence of any interactions occurring.

The linear components of the model accounted for 69% of the total variation, while the quadratic effects and interactions represented only 2 and 1% of the total variation, respectively (Appendix Table 18). Only the linear effects of the experimental variables X_2 and X_3 had

an effect upon the available forage ($P < 0.01$). Increasing the days of rest and decreasing the grazing pressure increased the available forage during the wet season of 1979. For 14 days increase in rest period there was an increase of 750 kg ha^{-1} of available forage and for each unit (1.6 kg DM) decrease in grazing pressure there was a 500 kg ha^{-1} increase in available forage. The analysis of variance for the wet season of 1979 is presented in Appendix Table 18.

Available Forage for the Dry Season of 1979 (DM)

For the second dry season, the available forage for each treatment combination is presented in Table 5. The available forage varied from 400 kg DM ha^{-1} to 5980 kg DM ha^{-1}, corresponding to the following treatment combinations: 25 [1 day grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate] and 15 (7 days grazing, 42 days rest, 6.6 kg DM on offer/100 kg BW, and 300 kg ha^{-1} of superphosphate), respectively. Only days rest (X_2) and grazing pressure (X_3) showed any effect upon available forage (P 0.01). Each of these two experimental variables was acting independently because no interactions were found.

The linear components of the model accounted for 54% of the total variation, while the quadratic effects and interactions represented less than 1 and 6% of the total variation, respectively (Appendix Table 19). For each 14 day increase in the rest period, there was an increase of 320 kg ha^{-1} of available forage and for each unit (1.6 kg DM) decrease in grazing pressure, an increase of 570 kg ha^{-1} of available forage was realized. The analysis of variance for the dry season of 1979 is presented in Appendix Table 19.

Available Forage for the Wet Season of 1980 (DM)

The average amount of available forage (DM) for each treatment combination during the wet season of 1980 is presented in Table 5.

The available forage varied from 340 kg DM ha^{-1} to 7510 kg DM ha^{-1}, corresponding to treatments: 26 [28 days grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate], and 31 (1 day grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate), respectively. Only the two experimental variables days rest (X_2) and grazing pressure (X_3) were found to be affecting the available forage ($P < 0.01$). The other two variables and the interactions were not significant.

The linear components of the model accounted for 57% of the total variation, while the quadratic effects and interactions represented only 3 and 4% of the total variation, respectively (Appendix Table 20). The other experimental variables, X_1 and X_4, had no significant effect upon the available forage.

As the rest period was increased by 14 days there was an increase of 760 kg ha^{-1} of available forage. On the other hand, each unit (1.6 kg DM) decrease in grazing pressure resulted in an increase of 650 kg ha^{-1} of available forage. The analysis of variance for the wet season of 1980 is presented in Appendix Table 20.

Summary of Available Forage (DM)

Available forage may be considered a more important response variable than aerial biomass since available forage takes into consideration only the components of the vegetation considered edible

by the grazing animal. The available forage was estimated by determining the botanical composition of the total aerial biomass and summing the grass and legume components. Over the five seasons during which this study was conducted the available forage was greatly influenced by the environmental factors which are discussed in the aerial biomass section. The experimental variables, days rest (X_2) and grazing pressure (X_3), each had a highly significant effect upon the available forage. The response of available forage to these two experimental variables was essentially linear over the range which was studied. The longer rest period permitted an accumulation of reserves for pasture regrowth and the lower grazing pressure retained more of the aerial parts of both the grasses and legumes affecting mainly the growing points, axillary buds, and traditional leaf area for the production of photosynthate which stimulated subsequent regrowth. It is significant that these two variables seem to act independently as no interactions between them were found within the range of levels in this experiment.

Similarities in responses to the same lengths of rest period and with the same grazing pressures were observed by Maraschin (1975) and Serrao (1976). In each of these two cases interactions were found between these two variables where maximum yields were obtained at high grazing pressures in combination with long rest periods and low grazing pressures with short rest periods. The above studies were conducted with <u>Cynodon dactylon</u> and <u>Desmodium intortum</u> which have quite different growth habits than the grasses and legumes included in this study. <u>Cynodon dactylon</u> is a stoloniferous grass with the

growing points close to the soil surface as compared with guineagrass and elephantgrass, each of which has apical meristems and lateral buds located much higher from the crown. The two grasses included in the current study are more sensitive to levels of defoliation and short rest periods because these grasses do not have rhizomes or stolons to store reserves. The legumes included in the current study are climbing and twining tropical legumes which no doubt are more sensitive to close defoliation than many other species.

Effect of Lengths of Rest Period and Levels of Grazing Pressure on Grass Yield (DM)

The effects of lengths of rest period and levels of grazing pressure on grass yield are presented in Table 6. The grass yield is that available before each grazing cycle and each 56 days for the continuous grazing treatments.

Grass Yield (DM) for the Wet Season of 1978

During this first experimental season no significant effects were shown by any of the four variables (X_1, X_2, X_3, X_4) (Table 6 and Appendix Table 21).

Grass Yield (DM) for the Dry Season of 1978

The grass yield for the dry season of 1978 for each treatment combination is given in Table 6. The grass yield varied from 400 kg DM ha^{-1} t0 4550 kg DM ha^{-1}, which was found on treatments 26 [28 days grazing, 0 days rest (continuous grazing), 1.6 kg DM on

Table 6. Grass yields (DM) by year, season, and treatment combination.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						kg ha^{-1}				
1	7	14	3.3	100	1	990	1650	1670	1560	1060
2	21	14	3.3	100	1	1540	2130	2600	2050	2720
3	7	42	3.3	100	1	1340	2160	3590	1930	2980
4	21	42	3.3	100	1	1240	2100	3080	1440	3780
5	7	14	6.6	100	1	1810	2930	3760	3570	3500
6	21	14	6.6	100	1	1130	2940	2410	1950	2020
7	7	42	6.6	100	1	1460	3340	4010	2940	3950
8	21	42	6.6	100	1	1240	3770	5490	4400	5440
9	7	14	3.3	300	1	1940	1270	2590	1720	2110
10	21	14	3.3	300	1	1950	2130	3330	2250	2590
11	7	42	3.3	300	1	1290	2170	3270	2390	3750
12	21	42	3.3	300	1	920	1750	3910	2260	5900
13	7	14	6.6	300	1	1400	1970	2440	2220	2000
14	21	14	6.6	300	1	1630	2020	1790	1600	1720
15	7	42	6.6	300	1	980	3380	5750	5510	6760
16	21	42	6.6	300	1	1790	2460	3490	2560	3680
17	1	0	1.6	0	1	1000	760	560	420	350
18	28	0	1.6	0	1	1380	640	910	390	300
19	1	56	1.6	0	2	1860	3060	5560	3620	7150
20	28	56	1.6	0	2	1470	1720	3920	2570	3820
21	1	0	8.3	0	1	1400	2640	3310	4010	5750
22	28	0	8.3	0	1	1090	2600	3320	3570	4730
23	1	56	8.3	0	2	2080	3370	6530	3790	5440
24	28	56	8.3	0	2	2070	4550	4940	4140	6370

Table 6.--continued.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						kg ha^{-1}				
25	1	0	1.6	400	1	1180	670	490	210	220
26	28	0	1.6	400	1	1110	400	740	390	120
27	1	56	1.6	400	2	1320	2040	4120	2040	3330
28	28	56	1.6	400	2	1520	2250	3890	2410	4010
29	1	0	8.3	400	1	1160	2040	2480	2970	2890
30	28	0	8.3	400	1	1300	1510	2620	2460	3060
31	1	56	8.3	400	2	1440	4260	6530	3580	7480
32	28	56	8.3	400	2	1590	4180	5780	5720	6160
33	1	28	5.0	200	1	1130	1900	2580	2270	2210
34	28	28	5.0	200	1	860	1490	2250	1860	2450
35	14	0	5.0	200	1	1500	1140	1380	1080	1500
36	14	56	5.0	200	1	1930	2870	3760	3300	4040
37	14	28	1.6	200	1	1140	1060	1230	1220	780
38	14	28	8.3	200	1	1390	2010	2750	2470	2600
39	14	28	5.0	0	1	1710	1700	2610	1930	2630
40	14	28	5.0	400	1	1470	1420	2780	2280	2080
41	14	28	5.0	200	3	1270	1780	2370	1640	2290

†D/G = days grazing, D/R = days rest, G/P = grazing pressure, F = fertilizer.
‡W/S = wet season, D/S = dry season.

offer/100 kg BW, and 400 kg ha^{-1} of superphosphate] and 24 (28 days grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate), respectively. Both rest period (X_2) and grazing pressure (X_3) had an effect upon the grass yield ($P < 0.01$). The application of superphosphate (X_4) also had a significant effect at the 10% level of significance. Each of these variables acted independently for grass yield since no interactions occurred.

The linear components of the model accounted for 74% of the total variation, while the quadratic effects and interactions represented only 2 and 1% of the total variation, respectively (Appendix Table 22).

An examination of the individual linear effects shows that the experimental variable, days grazing (X_1), did not have any effect on the amount of grass produced. The greatest effects were obtained from days rest (X_2) and grazing pressure (X_3). As the length of rest period increased from zero days (continuous grazing) the amount of grass yield tends to increase, whereas, when the grazing pressure is decreased from 1.6 to 8.3 kg DM on offer/100 kg BW, the grass yield was increased. For each 14 days increase in rest period, there was an increase of 440 kg ha^{-1} of grass yield. For each increment of decrease in the grazing pressure, there was an increase of 430 kg ha^{-1} of grass yield. The analysis of variance is presented in Appendix Table 22.

Grass Yield (DM) for the Wet Season of 1979

The grass yield for the wet season of 1979 for all treatment combinations is presented in Table 6. During this season the grass yield varied from 560 kg DM ha^{-1} to 6530 kg DM ha^{-1} for treatment combinations 17 [1 day grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate] and 23 (1 day grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate), respectively. Grass yield was again influenced by days rest (X_2) and grazing pressure (X_3) ($P < 0.01$), while the experimental variables days grazing and fertilizer level were not significant. There were no interactions between experimental variables during this season.

The linear components of the model accounted for 72% of the total variation, while the quadratic and interaction effects represented only 2 and 3%, respectively (Appendix Table 23). The grass yield was positively related to increasing lengths of rest period and negatively related to increasing amounts of forage on offer to the grazing animals. For each 14 days increase in the rest period, there was an increase of 800 kg ha^{-1} of grass yield; on the other hand, for each unit (1.6 kg DM) decrease in grazing pressure, there was an increase of 430 kg of grass yield. The analysis of variance is presented in Appendix Table 23.

Grass Yield (DM) for the Dry Season of 1979

The grass yield for the dry season of 1979 for each treatment combination is presented in Table 6. Grass yield varied from 210

kg DM ha^{-1} to 572 kg DM ha^{-1} for the following treatment combinations: 25 [1 day grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate] and 32 (28 days grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate), respectively. Again the grass yield was increased by increasing the days of rest and decreasing the grazing pressure ($P < 0.01$). The variables X_1 and X_4 were not significant and no interactions were found between the experimental variables. The linear components of the model accounted for 57% of the total variation, while the quadratic and interaction effects represented only 2 and 5% of the total variation, respectively (Appendix Table 24).

For each 14 days increase in rest period, there was a corresponding increase of 420 kg ha^{-1} of grass yield, while each unit (1.6 kg DM) decrease in grazing pressure increased the grass yield by 540 kg ha^{-1}. The analysis of variance is presented in Appendix Table 24.

Grass Yield (DM) for the Wet Season of 1980

The grass yield (DM) for the wet season of 1980 for each treatment combination is presented in Table 6. Grass yield varied from 120 kg DM ha^{-1} to 7150 kg DM ha^{-1} for treatments 26 [28 days grazing, 0 days rest (continuous grazing), 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate] and 19 (1 day grazing, 56 days rest, 1.6 kg DM on offer/100 kg BW, and 0 kg ha^{-1} of superphosphate), respectively. Grass dry matter yield was again affected by increasing the number of days rest and decreasing the grazing pressure ($P < 0.01$).

The other two experimental variables, X_1 and X_4, were not significant and no interactions were found between the experimental variables. The linear components of the model accounted for 59% of the total variation, while the quadratic and interaction effects represented only 5 and 3% of the total variation, respectively (Appendix Table 25). An increase of one unit (14 days) of rest increased the grass dry matter yield by 870 kg ha^{-1}, while a decrease in the grazing pressure increased the grass dry matter yield by 610 kg ha^{-1}. The analysis of variance is presented in Appendix Table 25.

Summary of Grass Yield (DM)

During the first rainy season (1978), with less than 2 months duration from May 12 to June 30, the experimental variables had no effect upon grass yield.

Beginning with the dry season of 1978 through the last wet season of 1980, the grass yield was positively related to increasing lengths of rest period. The two grasses, guineagrass and elephant-grass, used in this experiment are tall growing species with a high capacity for dry matter production and each of them are favored by long rest periods. As the length of the rest period was increased the dominance of each of these grasses was evident, leaving very little space for other species, such as legumes and weeds. The grass yield also increased with time as these two species of grasses became securely established. The mean grass yield for the wet season of 1978 was 1530 kg DM ha^{-1}, while for the last wet season of 1980, the grass yield was 3630 kg DM ha^{-1}. It is evident that the amount

of grass increased considerably from 1978 to 1980 (Figs. 6, 7, and 8), due mainly to its rapid growth capacity and ability to eliminate the other companion species. Vicente-Chandler (1975) reported that elephantgrass and guineagrass are the most productive tropical grasses reaching values of 78 and 45 tons DM ha^{-1} $year^{-1}$. INIAP (1980) reported that under a cutting system, the rate of growth for elephantgrass and guineagrass is in the order of 166 kg and 149 kg DM ha^{-1} day^{-1}, respectively. These values corresponded to those obtained in this experiment during the wet season of 1979 but as the year progressed, these values decreased and reached the lowest rate at the end of the dry season of that particular year, being in the order of 32 and 28 kg DM ha^{-1} day^{-1} for elephantgrass and guineagrass, respectively.

Grazing pressure expressed as the amount of forage offered per 100 kg BW increased the grass yield as the grazing pressure was decreased. The lowest yields were obtained under the highest grazing pressure and the highest yields were obtained in the treatments with the lowest grazing pressure. If the two experimental variables, rest period and grazing pressure are considered in combination, then the lowest grass yields were obtained under continuous grazing and the highest grazing pressure, while the highest yields were observed on treatment combinations having the longest rest period with the lowest grazing pressure. As the grazing pressure was increased, the amount of plant shoots that were removed by the grazing animal also increased and when this was accompanied by an increase in frequency of defoliation (short rest periods or continuous grazing), the

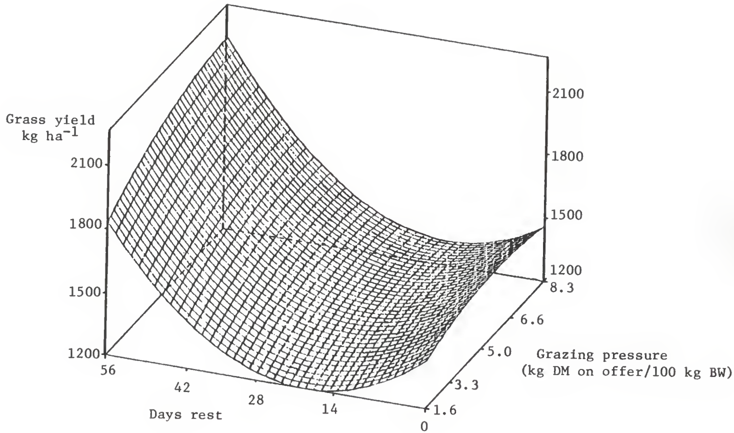

Fig. 6. Effect of rest period and grazing pressure upon grass yield (DM) for the wet season of 1978.

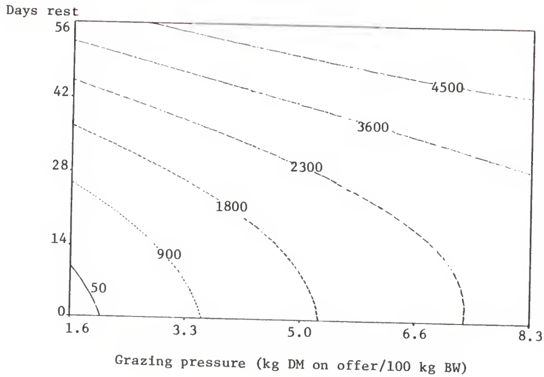

Fig. 7. Contours of grass yield (DM) as affected by length of rest period and levels of grazing pressure in the wet season of 1980.

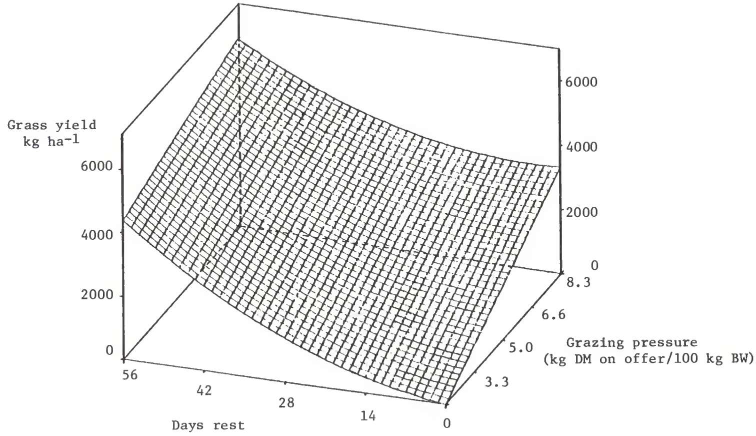

Fig. 8. Effect of rest period and grazing pressure upon grass yield (DM) for the wet season of 1980.

intensity of plant removal was the major determinant of grass yield. This was true for both guineagrass and elephanatgrass and the effect of severe defoliation was to reduce the vigor and the regrowth capacity of these two species. At this point, some bare soil areas were observed and weed invasion occurred. This was very evident under short rest periods when combined with high grazing pressure.

The animals had a tendency to selectively graze the grass species during the wet seasons and to selectively graze the legumes during the dry seasons. Similar results have been reported by Humphreys (1978) who observed a selective consumption of _Panicum maximum_ in preference to _Stylosanthes guianensis_ while in the dry season, _S. guianensis_ was well-consumed.

It is well known that tall-growing grasses are very susceptible to a higher degree of defoliation, especially if these species are subjected to low cutting heights or high grazing pressures. Most of the leaves, growing points, and axillary buds are located much higher than on short-growing species. The two tall-growing species in this study have long internodes with the axillary buds located far apart on the stem so they are very vulnerable to intense defoliation.

Effects of Lengths of Rest Period and Levels of Grazing Pressure Upon Legume Yield (DM)

Since one of the main objectives of this research was to determine the optimum combinations of the components of grazing management which would favor the legume component of the pasture and permit a higher order of persistence, the legume yield and the changes which occurred during the five seasons are of primary interest.

Legume Yield (DM) for the Wet Season of 1978

Legume yields for the wet season of 1978 for each treatment combination are presented in Table 7. Legume yield varied from 410 kg DM ha^{-1} to 1380 kg DM ha^{-1} for treatments 2 (21 days grazing, 14 days rest, 3.3 kg DM on offer/100 kg BW, and 100 kg ha^{-1} of superphosphate) and 14 (21 days grazing, 14 days rest, 6.6 kg DM on offer/100 kg BW, and 300 kg ha^{-1} superphosphate), respectively.

Length of rest period was the only factor which appeared to have much effect upon legume yield ($P < 0.01$). The other three experimental variables, X_1, X_3, and X_4, and all of the interactions were not significant. The linear components of the model accounted for 16% of the total variation, while the quadratic and interaction components represented only 4 and 8% of the total variation, respectively (Appendix Table 26). For each unit (14 days) increase in the rest period, there was an increase of only 60 kg of legume yield. The analysis of variance is presented in Appendix Table 26.

This lack of response to the experimental variables was expected since the wet season of 1978 was very short, so the experimental variables did not have time to create differences in response.

Legume Yield (DM) for the Dry Season of 1978

Legume yield for each treatment combination during the dry season of 1978 is presented in Table 7. The legume yields varied from 380 kg DM ha^{-1} to 1160 kg DM ha^{-1} for treatments 28 (28 days grazing, 56 days rest, 1.6 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate) and 24 (28 days grazing, 56 days rest, 8.3 kg DM on offer/

Table 7. Dry matter means for legume by year, season, and treatment combination.

	Treatments					1978	1978	1979	1979	1980
No.	D/G (X_1)	D/R (X_2)	G/P (X_3) % BW	F kg ha^{-1}	Reps	W/S	D/S	W/S	D/S	W/S
						kg ha^{-1}				
1	7	14	3.3	100	1	640	620	560	510	480
2	21	14	3.3	100	1	410	590	510	330	420
3	7	42	3.3	100	1	1240	590	250	710	150
4	21	42	3.3	100	1	580	410	280	350	130
5	7	14	6.6	100	1	520	670	900	640	560
6	21	14	6.6	100	1	990	740	660	910	730
7	7	42	6.6	100	1	1150	680	220	110	20
8	21	42	6.6	100	1	670	870	320	310	280
9	7	14	3.3	300	1	1210	590	500	700	430
10	21	14	3.3	300	1	780	680	900	770	940
11	7	42	3.3	300	1	1010	650	340	320	80
12	21	42	3.3	300	1	600	470	500	210	30
13	7	14	6.6	300	1	890	640	400	770	520
14	21	14	6.6	300	1	1380	840	810	650	600
15	7	42	6.6	300	1	810	990	350	470	470
16	21	42	6.6	300	1	1240	530	190	150	0
17	1	0	1.6	0	1	650	440	270	270	300
18	28	0	1.6	0	1	610	430	460	370	260
19	1	56	1.6	0	2	860	540	190	40	0
20	28	56	1.6	0	2	850	540	490	190	0
21	1	0	8.3	0	1	870	850	620	630	370
22	28	0	8.3	0	1	710	930	490	370	110
23	1	56	8.3	0	2	1150	420	80	40	20
24	28	56	8.3	0	2	1320	1160	950	300	60

Table 7.--continued.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						kg ha^{-1}				
25	1	0	1.6	400	1	810	450	450	180	180
26	28	0	1.6	400	1	700	380	240	440	220
27	1	56	1.6	400	2	1000	400	140	40	30
28	28	56	1.6	400	2	1180	380	190	150	30
29	1	0	8.3	400	1	530	570	650	640	630
30	28	0	8.3	400	1	1040	890	910	640	980
31	1	56	8.3	400	2	900	570	420	100	0
32	28	56	8.3	400	2	980	680	560	110	0
33	1	28	5.0	200	1	1330	730	480	490	680
34	28	28	5.0	200	1	560	780	970	780	770
35	14	0	5.0	200	1	1130	560	410	570	320
36	14	56	5.0	200	1	1200	830	650	0	0
37	14	28	1.6	200	1	620	780	740	640	580
38	14	28	8.3	200	1	940	720	800	690	870
39	14	28	5.0	0	1	1140	850	510	780	510
40	14	28	5.0	400	1	440	650	610	520	420
41	14	28	5.0	200	3	1020	540	580	740	530

†D/G = days grazed, D/R = days rest, G/P = grazing pressure, F = fertilizer.
‡W/S = wet season, D/S = dry season.

100 kg BW, and 0 kg ha^{-1} of superphosphate), respectively. The legume yield was increased as the result of reducing the grazing pressure ($P < 0.01$). There was an interaction between days grazing (X_1) and grazing pressure (X_3) but this interaction did not occur again during the remaining three seasons. There appeared to be no linear effect for days grazing (X_1), days rest (X_2), and fertilizer level (X_4). The linear components of the model accounted for only 31% of the total variation, while the quadratic effects represented only 1% and the interactions 12% (Appendix Table 27).

During the dry season of 1978, there was a tendency for the legume yield to increase as the grazing pressures decreased.

Legume Yield (DM) for the Wet Season of 1979

The legume yield for the wet season of 1979 for each treatment combination is presented in Table 7. The legume yield during the second wet season varied from 80 kg DM ha^{-1} to 970 kg DM ha^{-1} for treatments 23 (1 day grazing, 56 days rest, 8.3 kg DM on offer/100 kg BW, and o kg ha^{-1} of superphosphate) and 34 (28 days grazing, 28 days rest, 5.0 kg DM on offer/100 kg BW, and 200 kg ha^{-1} of superphosphate), respectively.

Only the length of rest period (X_2) and grazing pressure (X_3) were found to have an effect upon legume yield ($P < 0.01$). There were no effects of X_1 and X_4 nor any of the interactions between the experimental variables.

The linear components of the model accounted for 34% of the total variation, while the quadratic and interaction effects represented

only 6 and 7% of the total variation, respectively (Appendix Table 28). During the 1979 wet season, the yield of legumes began to show a pattern associated with the length of the rest period. For each 14 days increase in rest period, there was a decrease of 56 kg ha^{-1} of legume yield. Also, during this season, grazing pressure began to show an effect upon legume yield. For each unit (1.6 kg DM) decrease in grazing pressure, there was an increase of 65 kg ha^{-1} of legume yield. The analysis of variance is presented in Appendix Table 28.

Legume Yield (DM) for the Dry Season of 1979

The legume yield for the dry season of 1979 for each treatment combination is presented in Table 7. Legume yield varied from 0 kg DM ha^{-1} to 910 kg DM ha^{-1} for treatments 36 (14 days grazing, 56 days rest, 5.0 kg DM on offer/100 kg BW, and 200 kg ha^{-1} of superphosphate) and 6 (21 days grazing, 14 days rest, 6.6 kg DM on offer/100 kg BW, and 100 kg ha^{-1} of superphosphate), respectively.

Legume yield was affected by length of rest period (X_2) ($P < 0.01$) and by grazing pressure (X_3) ($P < 0.05$). Days grazing and fertilizer levels had no significant effect and there were no interactions among the experimental variables. For length of rest period (X_2) there was both a linear and quadratic effect upon legume yield ($P < 0.01$). The linear and quadratic components of this experimental variable accounted for 43 and 27% of the total variation, while the interactions among the experimental variables accounted for only 3%, respectively (Appendix Table 29).

The quadratic effect of length of rest period (X_2) strongly suggests that the range of rest periods included in this experiment may have adequately covered the point of maximum legume yield. The highest legume yields were obtained in the region of 14 to 28 days rest and the yields decreased when the rest periods were reduced to zero or increased up to 56 days. The effect of grazing pressure (X_3) appears to be almost linear. For each unit (1.6 kg DM) that grazing pressure was reduced from 1.6 to 8.3 kg DM on offer/100 kg BW, the amount of legume yield increased by 31 kg DM ha^{-1}. The analysis of variance is presented in Appendix Table 29.

Legume Yield (DM) for the Wet Season of 1980

The legume yield for the wet season of 1980 for each species combination is given in Table 7. Legume yields varied from 0 kg DM ha^{-1} for treatments with the longest rest period (56 days) to 980 kg DM ha^{-1} for treatment 30 [28 days grazing, 0 rest period (continuous grazing), 3.3 kg DM on offer/100 kg BW, and 400 kg ha^{-1} of superphosphate].

There was both a linear and quadratic effect of length of rest period (X_2) upon legume yield ($P < 0.01$). There was a linear effect of grazing pressure ($P < 0.05$). The effects of days grazing and fertilizer level were not significant and neither were any of the interactions of the experimental variables.

The linear and quadratic effects accounted for 45 and 24% of the total variation, respectively, while the interactions represented only 5% (Appendix Table 30).

The quadratic effect of rest period (X_2) gives a better representation of the legume yield which maximizes within the range of 14 and 28 days. As the length of the rest period is either decreased or increased, the legume yield is decreased.

As the grazing pressure decreases, the amount of legume yield increased by 37 kg ha^{-1}. The analysis of variance is presented in Appendix Table 30.

Observations and Summary of Legume Yield (DM)

Some very significant changes occurred in the legume population of these experimental pastures, some of which were recorded and subjected to analysis, whereas others were observations made over the five seasons of this trial. Drastic changes occurred as a result of the treatments imposed from the end of the wet season of 1978 to the end of the wet season of 1980. Some of these observations are recorded here.

When the experiment was initiated on May 12 of 1978, the average legume yield for the period until June 30 was about 928 kg ha^{-1}. During this initial period, only rest period showed any effect ($P < 0.01$) upon legume yield. It is difficult to find any satisfactory explanation for the effect of any experimental variable over this short period of time, but differences in the growth rate of grasses and legumes or the short-term effects of insects like red spider on centro could be a partial explanation (Fig. 9).

During the first dry season (July to December, 1978), the legume yield declined from 640 kg ha^{-1} which indicated a linear response to

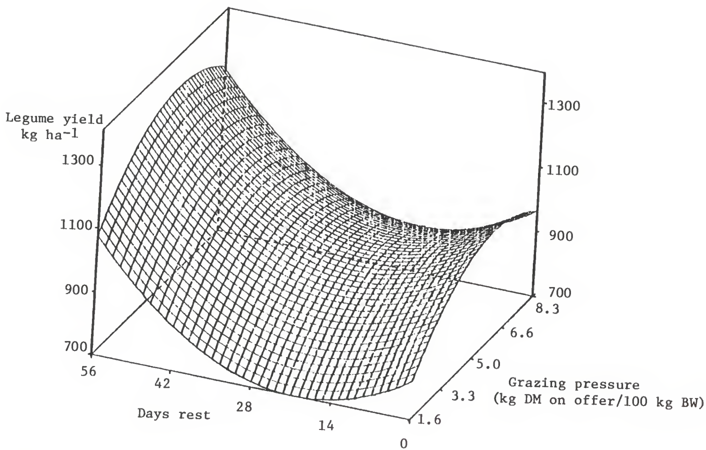

Fig. 9. Effect of rest period and grazing pressure upon legume yield (DM) for the wet season of 1978.

grazing pressure resulting in various degrees of defoliation, selectivity, and effect of trampling. Defoliation and selectivity were probably the main determinants on the amount of both legumes. A small difference is also recorded in the behavior of these two species in that centro appeared to be more tolerant of heavy grazing pressure and the area covered by glycine increased as the grazing pressure decreased. During the dry season of 1979, it was also observed that the grazing animals were selectively consuming more legumes than during the wet season, probably because of the lower quality and reduced quantity of grass for that period. Humphreys (1978) and Norman (1970) observed similar preferences of animals grazing tropical grass-legume pastures.

During the wet season of 1979 (January-June), the average legume yield was 473 kg ha^{-1} which was considerably lower when compared with the predecing dry season (1978) which can be explained by the much greater rate of growth by both of these companion grasses and by their stronger competitive ability which shaded the legumes, especially in the treatment with long rest periods. During the 1979 wet season, some environmental factors such as humidity, temperature, light, and N played a very important role in the high growth rates of the tropical grasses. The dominance of the C_4 grass species began to manifest itself over the C_3 tropical legumes. Mott stated that "physiological differences between tropical grasses and legumes have important implications for legume-grass associations. Since their optima for light, temperature, and moisture differ, it is much more difficult to select compatible grasses and legumes in the tropics than among temperate species where the responses to

environmental factors are similar." (1981, p. 35-41). He also added that the viney growth habit of several genera of tropical legumes (Calopogonium, Centrosema, some species of Desmodium, Neonotonia, Macroptilium, and Pueraria); they confer an advantage over C_4 tropical grasses in that they are able to climb to the top of the canopy. Devising defoliation strategies that will maintain the regrowth potential of viney legumes is very important.

The advantage of short rest periods during the wet seasons in terms of legume population was evident, giving these species more opportunity to survive, persist, bloom, and produce some seed, even at heavy grazing pressures. Under high levels of defoliation, the competitive and shading effects from both of the grasses was greatly limited. Each of the tropical legumes bloomed profusely at the beginning of the dry season (July-August).

During the dry season of 1979 (July-December), the mean legume yield was 397 kg ha^{-1}. During this second dry season a few pastures with the longest rest periods were almost 100% grass with no legumes nor weeds being observed. The decrease in legume yield may be partly explained by the excessive compititive ability of the grasses and also by the selective pressure on the legumes during this season. Pastures subjected to continuous grazing or short rest periods showed a greater proportion of legume dry matter in the total amount of available forage. Both legume species, centro and glycine, survived the effect of frequency and severity of defoliation when short rest periods were combined with high grazing pressures.

During the month of June and part of July of 1979, a severe attack of red spider was observed, especially on centro, while glycine appeared to be more tolerant and was damaged less than centro which led to the dominance of glycine during this whole season. Linear and quadratic effects of rest period (X_2) were observed ($P < 0.01$) while the linear effect of grazing pressure (X_3) was noted ($P < 0.05$). Field observations suggested that rest period was a greater determinant of legume survival, productivity, and persistence than was grazing pressure.

For the wet season of 1980 (January-June), there was also a decrease in the average legume yield at 294 kg ha^{-1}. In the last wet season, some pastures showed a complete dominance of grass, completely excluding both legumes and weeds. These changes were observed on treatments with the longest rest period which was confirmed by the analysis which showed rest period (X_2) with both linear and quadratic effects ($P < 0.01$). The effect of grazing pressure (X_3) was linear ($P < 0.05$) which suggested that rest period was the major determinant for the survival and productivity of the legumes (Figs.10 and 11).

The treatments with continuous grazing or short rest periods in combination with the highest grazing pressures drastically affected the yields of legumes, grasses, and weeds. This was especially true for the planted grasses and legumes, which were in some cases almost completely eliminated by the close and frequent defoliation which removed the major portion of the young active leaf material and apical meristems leading to a reduction in rate of recovery and ability to

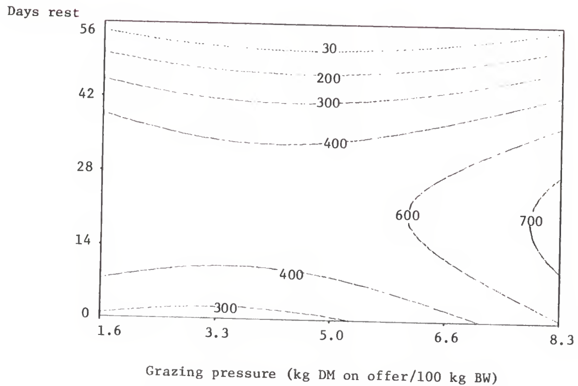

Fig. 10. Contours of legume yield (DM) as affected by length of rest period and levels of grazing pressure in the wet season of 1980.

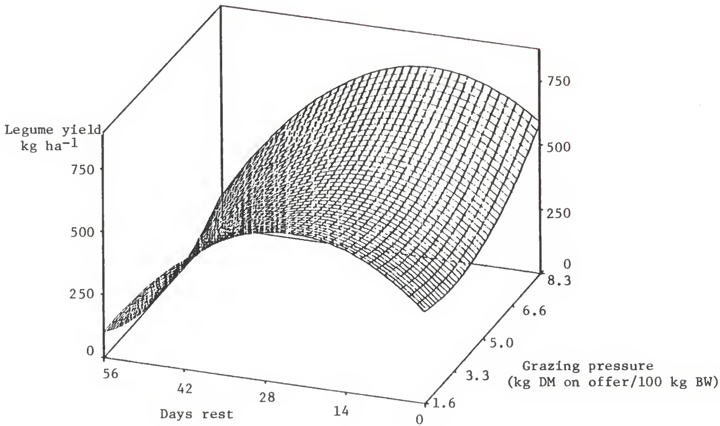

Fig. 11. Effect of rest period and grazing pressure upon legume yield (DM) for the wet season of 1980.

compete with the invading weed species. At the end of the wet season of 1980, some pasture which were subjected to the most intensive systems of grazing were almost completely invaded by weed species. Whether the lower survival under heavy grazing regimes was due to selective pressure by the animals, trampling, or the competitve advantage of the weeds, the final result was a steady decline in the density of sown species. Pastures which were subjected to moderate levels of rest period and grazing pressures had a higher survival rate, greater vigor, density, and a better legume-grass balance. On the other hand, long rest periods and light grazing pressure permitted the grasses to increase in dominance eliminating other species with a lower growth rate and ability to compete for space, environmental factors, and pressure of the grazing animals. The main concern of tropical legumes is whether they can persist and produce efficiently under the unfavorable effects of the tropical environnent. Some native legumes that appeared on the pastures were included as part of the available forage and of the legume yield. The most important of these were: Desmodium triflorum, D. canum, D. barbatum, and lesser amounts of Calopogonium mucunoides, Phaseolus sp. and Vigna luteola. The following legumes were recorded as part of the weed components since they were almost completely rejected by the grazing animals: Mimosa pudica, Mucuna pruriens, Cassia tora, and C. occidentalis.

Effect of Lengths of Rest Period and Levels of Grazing Pressure on the Yield of Weeds (DM)

The incidence of weed populations would be exptected to be related to the seed reserves of different weed species in an experimental site. Whether weeds appear under certain environmental circumstances will to a great extent be determined by the presence and abundance of seed of the different weed species. The results of this experiment appear to be no exception to this rule as the effect of the various grazing management systems was not nearly as consistent as for the two species of grasses and legumes. This will become evident as the results and the analyses are examined.

Yield of Weeds (DM) for the Wet Season of 1978

The yield of weeds for the wet season of 1978 for each treatment combination is presented in Table 8. The yield of weeds varied from 0 kg DM ha^{-1} to 210 kg DM ha^{-1} during the first one and one-half months of this trial.

During the first few weeks of the trial there appeared to be an effect of fertilizer upon the weed population ($P < 0.05$), but there was no linear effect of days grazing, days rest, and grazing pressure during this period upon the yield of weeds. The quadratic effects of days rest (X_2) and fertilizer level (X_4) was also apparent during this period ($P < 0.05$). An interaction between X_2 and X_3 also appeared ($P < 0.05$) and X_3 and X_4 ($P < 0.01$). These differences in interactions were probably due to seed reserves in the soil over which we exerted very little control at the beginning of the experiment.

Table 8. Dry matter means for weeds for year, season, and treatment combination.

No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	1978 W/S‡	1978 D/S‡	1979 W/S‡	1979 D/S‡	1980 W/S‡
						kg ha^{-1}				
1	7	14	3.3	100	1	150	130	860	790	920
2	21	14	3.3	100	1	10	0	90	140	210
3	7	42	3.3	100	1	40	0	0	0	0
4	21	42	3.3	100	1	60	10	130	60	20
5	7	14	6.6	100	1	30	80	170	250	420
6	21	14	6.6	100	1	40	50	40	10	10
7	7	42	6.6	100	1	90	0	0	0	10
8	21	42	6.6	100	1	30	0	10	0	40
9	7	14	3.3	300	1	0	40	220	100	420
10	21	14	3.3	300	1	110	110	200	200	480
11	7	42	3.3	300	1	0	60	0	0	0
12	21	42	3.3	300	1	70	0	20	30	0
13	7	14	6.6	300	1	0	0	10	10	30
14	21	14	6.6	300	1	180	70	80	40	90
15	7	42	6.6	300	1	70	20	0	0	10
16	21	42	6.6	300	1	40	90	50	60	0
17	1	0	1.6	0	1	90	40	380	790	1260
18	28	0	1.6	0	1	0	50	370	510	890
19	1	56	1.6	0	2	20	10	10	0	0
20	28	56	1.6	0	2	60	0	0	30	0
21	1	0	8.3	0	1	0	40	10	40	140
22	28	0	8.3	0	1	0	40	100	20	20
23	1	56	8.3	0	2	0	0	10	10	0
24	28	56	8.3	0	2	60	30	40	10	0

Table 8.--continued.

No.	Treatments D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	1978 W/S‡	1978 D/S‡	1979 W/S‡	1979 D/S‡	1980 W/S‡
						kg ha^{-1}				
25	1	0	1.6	400	1	40	80	440	1730	2600
26	28	0	1.6	400	1	90	0	220	240	2470
27	1	56	1.6	400	2	30	0	10	60	190
28	28	56	1.6	400	2	0	0	0	0	0
29	1	0	8.3	400	1	0	10	20	30	150
30	28	0	8.3	400	1	90	100	60	40	110
31	1	56	8.3	400	2	120	30	0	20	0
32	28	56	8.3	400	2	130	0	10	0	0
33	1	28	5.0	200	1	100	40	20	20	70
34	28	28	5.0	200	1	150	190	320	240	200
35	14	0	5.0	200	1	50	10	20	0	10
36	14	56	5.0	200	1	0	40	30	20	0
37	14	28	1.6	200	1	70	50	200	500	830
38	14	28	8.3	200	1	210	160	100	30	80
39	14	28	5.0	0	1	0	0	100	10	40
40	14	28	5.0	400	1	40	30	20	0	60
41	14	28	5.0	200	3	70	30	50	30	100

†D/G = days grazing, D/R = days rest, G/P = grazing pressure, F = fertilizer.
‡W/S = wet season, D/S = dry season.

During the first season a significant linear, quadratic, and interaction effects were found which accounted for 16, 14, and 23% of the total variation, respectively (Appendix Table 31).

Yield of Weeds (DM) for the Dry Season of 1978

The yield of weeds for the dry season of 1978 is presented in Table 8 for all the treatment combinations. The yield of weeds varied from 0 kg DM ha^{-1} to 190 kg DM ha^{-1}. There is a linear effect of days rest (X_2) on the yield of weeds ($P < 0.01$), but the linear effects of X_1, X_3, and X_4 were not significant. A quadratic effect of X_2 was also noted ($P < 0.06$) and no interactions between the experimental were found. The linear and quadratic components of the model accounted for 16 and 22% of the total variation, respectively, while the interaction effects represented only 3% of the total variation (Appendix Table 32). The yield of weeds tended to decrease as the length of the rest period was increased from 0 to 56 days, but this response was very small.

Yield of Weeds (DM) for the Wet Season of 1979

The yield of weeds for the wet season of 1979 for each treatment combination is presented in Table 8. The yield of weeds varied from 0 to 860 kg DM ha^{-1}. It was during this period that the effects of rest period and grazing pressure upon the yield of weeds began to emerge. There was a linear effect of rest period (X_2) and grazing pressure (X_3) upon the yield of weeds ($P < 0.01$). There was also a significant interaction of X_2 and X_3 ($P < 0.01$). The length of

grazing period and fertilizer level had no effect upon the yield of weeds. The linear and interactions components of the model accounted for 35 and 17% of the total variation, respectively (Appendix Table 33).

The yield of weeds tended to decrease as the length of the rest period increased from continuous grazing to 56 days of rest, and a similar trend was observed as the grazing pressure increased from 8.3 to 1.6 kg DM on offer/100 kg BW. Each unit of rest (14 days) decreased the yield of weeds by 50 kg ha^{-1} and for each unit increase in grazing pressure the yield of weeds was decreased by 43 kg ha^{-1}. The analysis of variance is presented in Appendix Table 33.

Yield of Weeds (DM) for the Dry Season of 1979

The yield of weeds during this season varied from 0 to 1730 kg DM ha^{-1} (see Table 8).

The number of days grazing (X_1), days rest (X_2), and grazing pressure (X_3) affected the yield of weeds ($P < 0.01$). There were also significant interactions between $X_1 \times X_2$, $X_2 \times X_3$, and $X_1 \times X_3$. The linear and the interaction components of the model accounted for 35 and 30% of the total variation, respectively, while the quadratic component represented only 6% (Appendix Table 34). The yield of weeds decreased as the length of grazing period, length of rest period, and the grazing pressure was increased.

Yield of Weeds (DM) for the Wet Season of 1980

The yield of weeds for the 1980 wet season is presented in Table 8. The yield of weeds varied from 0 to 2600 kg DM ha^{-1}. The yield of weeds was affected by days rest (X_2), grazing pressure (X_3), and fertilizer level (X_4) ($P < 0.01$). There was also a quadratic component for grazing pressure (X_3) ($P < 0.01$). The interactions between $X_2 \times X_3$, $X_2 \times X_4$, and $X_3 \times X_4$ were also significant at the 1% level of probability. The linear, quadratic, and interaction components of the model accounted for 45, 9, and 30% of the total variation, respectively (Appendix Table 35). The yield of weeds tends to decrease as the length of the grazing period and rest period increases, as was also the case with increasing grazing pressure. A positive trend was also observed as the fertilizer level was increased.

Observations and Summary of Yield of Weeds

During the five seasons during which this experiment was conducted from May, 1978 to May, 1980, some of the most drastic changes which occurred were observed in the yield of weeds.

During the first wet season (May-June, 1978), the main effects and interactions which occurred can probably be explained on the basis of the seed reserves of certain species of weeds at the experimental site. The fact that the application of fertilizer appeared to have an effect while no other experimental variable manifested itself is significant. It is quite well known that certain weed species respond readily to fertilizer treatments and although

the yields of weeds were low during the first season, there presence in response was noteworthy. During the dry season of 1978, there was a quadratic response to P fertilizer and it appeared that some species of weeds were the only species which responded positively to P. There was also some evidence that the yield of weeds was responding during the first dry season to the length of rest period (X_2), since there was a decline in the weed population as the length of rest period increased. This may have been due to the competition from the small-growing tropical grasses (Fig. 12).

During the wet season of 1979, the effect of days rest (X_2) and grazing pressure (X_3) resulted in a decline of the yield of weeds ($P < 0.01$). There was also a strong interaction between these two variables ($P < 0.01$). This interaction suggests that the yield of weeds is reduced by increasing the length of the rest period in association with low grazing pressures. When shorter rest periods or continuous grazing are combined with high grazing pressure, there was an increase in the yield of weeds. It was evident that short rest periods and high grazing pressures had a detrimental effect upon the pasture. Weeds were encouraged due to the opening of the sward and by the selective grazing of the more palatable species. Most of the weedy species were not consumed nor were they much affected by the trampling by the grazing animals. The mean dry matter yield for the weeds was 94 kg ha^{-1}.

During the dry season of 1979, increases in the days grazing (X_1), days rest (X_2), and grazing pressure (X_3) resulted in a decline in the yield of weeds ($P < 0.01$). The experimental variables, X_2 and X_3,

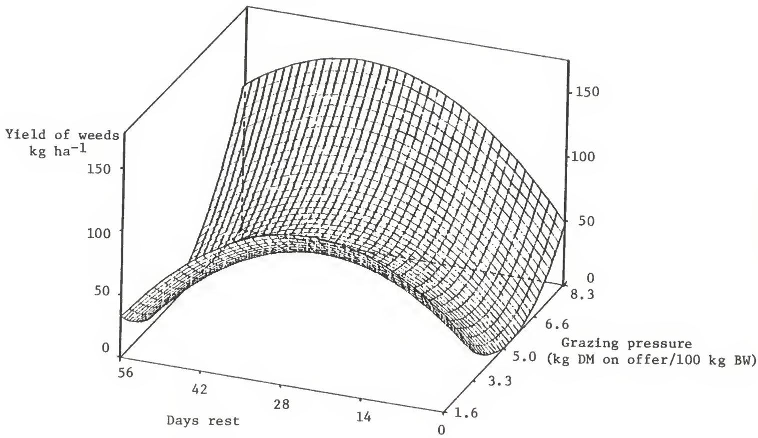

Fig. 12. Effect of rest period and grazing pressure upon yield of weed (DM) for the wet season of 1978.

appeared to be the principal determinants of the yield of weeds. There were also interactions between $X_1 \times X_2$, $X_1 \times X_3$, and $X_2 \times X_3$, which indicated that the yield of weeds was reduced by increasing the rest period with short grazing period and also by increasing the rest period with low grazing pressure. When long grazing periods are combined with short rest periods, there is an increase in the yield of weeds and this also occurred with short rest periods and high grazing pressure. These last two interactions depressed the amount of grass and legume dry matter which favored the weeds. There was an increase in the average yield of weeds to 125 kg DM ha^{-1} which suggested that the weed problem was increasing with time. During the wet season of 1980, the linear effects of rest period (X_2), grazing pressure (X_3), and P fertilizer (X_4) were very evident ($P < 0.01$). There was also a quadratic effect of X_3 ($P < 0.01$). The interactions between $X_2 \times X_3$, $X_2 \times X_4$, and $X_3 \times X_4$ were also significant ($P < 0.01$). From the results of these analyses, it appeared that days rest and grazing pressure were the principal determinants of the yield of weeds (see Figs. 13 and 14). The interactions indicate that the yield of weeds declined as the rest period increased in combination with low grazing pressures, while the yield of weeds increased when short rest periods were conbined with high grazing pressures. Weeds apparently respond positively to increasing levels of P. It was also observed that when short rest periods were combined with high fertilizer levels and high grazing pressures, that the yield of weeds increased considerably reaching values of 2600 and 2470 kg DM ha^{-1}. Near zero levels of weeds were found with treatments

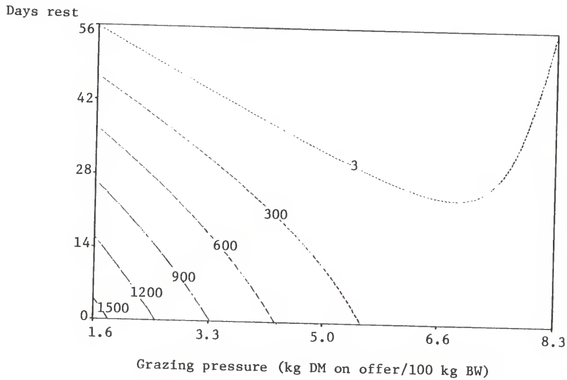

Fig. 13. Contours of yield weed (DM) as affected by length of rest period and levels of grazing pressure in the wet season of 1980.

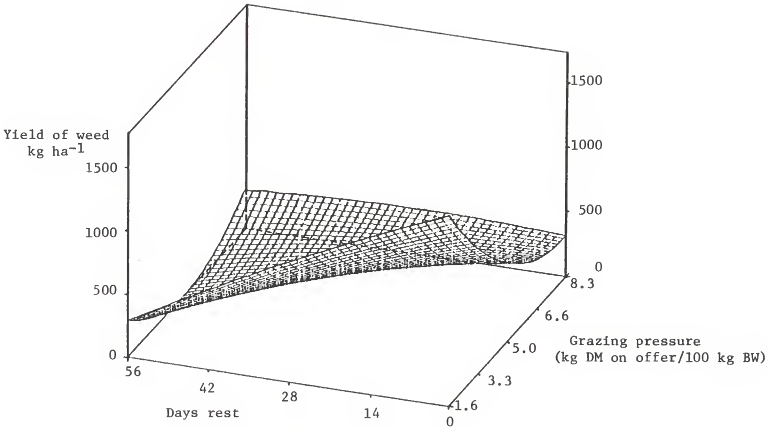

Fig. 14. Effects of rest period and grazing pressure upon yield of weed (DM) for the wet season of 1980.

with long rest periods and/or low grazing pressures with low P levels. It is well known that tall-growing grasses and climbing legumes have the potential to exploit the soil and aerial environments which may limit the growth of companion or invading species, especially when the management practices favor their maximum production. Frequent and intensive defoliation of the two species may be highly detrimental to their vigor and regrowth capacity, so that the sward can easily be dominated by undesirable species.

Maraschin (1976) reported similar results with weeds which were affected by the rest period and grazing pressure and he concluded that short rest periods and high grazing pressure create the most favorable conditions for weeds invasion.

Jensen and Schumacher (1970) reported that the botanical composition is not only affected by the grazing animal, but also by some environmental factors such as the season, rainfall, temperature, and soil nutrients which may allow certain weedy species to invade the pasture sward.

The predominant weed species in this study were: *Sida acuta*, *Solanum carolinensis*, *Amaranthus* sp., *Capsicum* sp., *Aescplepias* sp., *Mimosa pubica*, *Cassia tora*, *C. occidentalis* (broadleaf weeds); *Paspalum fasciculatum*, *P. paniculatum*, *P. conjugatum*, *Digitaria sanguinalis*, *Eleusine indica* (Grasses); and *Cyperus rotundus* (Sedge). Some of these weeds were also reported by Santillan (1971) growing in Jaraguagrass (*Hyparrhenia rufa*).

Visual Estimation of Forage Components

Visual estimations of forage components were made as part of a double sampling procedure which was checked against the botanical separations. This section presentes the results for the visual estimations of the percentage grass and the percentage legume. These estimations were made and adjusted statistically with the use of a linear regression model for each of the 41 treatments and for each of the five seasons.

Visual Estimation of Percentage Grass

The visual estimations of the percentage grass on a dry matter basis are given in Table 9 for each treatment combination and for each season. In the wet season of 1978, the percentage grass varied from 50 to 80% which represented the variation that occurred during the first two and one-half months of the experiment. There were no significant effects of treatment during this first season. The analysis of variance is presented in Appendix Table 36.

In the dry season of 1978, the visual estimates are also presented in Table 9, and the percentage grass varied from 52 to 89%. The linear effects of rest period and grazing pressure ($P < 0.01$) became evident during the first dry season, but the effects of days grazing and fertilizer level were not significant. Also there were no interactions between the experimental variables. The linear components of the model accounted for 64% of the total variation, while the quadratic and interaction effects represented 1 and 6% of the total variation, respectively (Appendix Table 37). During the 1979 season,

Table 9. Visual estimation of dry matter grass percent for year, season, and treatment combination.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						%				
1	7	14	3.3	100	1	58	69	53	53	45
2	21	14	3.3	100	1	80	78	78	81	77
3	7	42	3.3	100	1	50	77	90	70	93
4	21	42	3.3	100	1	70	80	87	82	95
5	7	14	6.6	100	1	76	78	76	79	75
6	21	14	6.6	100	1	50	68	72	68	69
7	7	42	6.6	100	1	51	81	91	94	98
8	21	42	6.6	100	1	66	79	88	91	90
9	7	14	3.3	300	1	63	64	72	65	67
10	21	14	3.3	300	1	65	68	73	67	61
11	7	42	3.3	300	1	60	76	86	84	95
12	21	42	3.3	300	1	50	80	87	89	98
13	7	14	6.6	300	1	63	72	80	69	74
14	21	14	6.6	300	1	50	63	63	66	69
15	7	42	6.6	300	1	50	68	91	89	88
16	21	42	6.6	300	1	55	75	92	90	100
17	1	0	1.6	0	1	56	59	46	27	16
18	28	0	1.6	0	1	67	57	49	30	26
19	1	56	1.6	0	2	69	82	95	97	100
20	28	56	1.6	0	2	63	77	91	90	100
21	1	0	8.3	0	1	63	69	81	82	88
22	28	0	8.3	0	1	60	66	81	88	96
23	1	56	8.3	0	2	70	89	96	98	99
24	28	56	8.3	0	2	54	75	78	90	98

Table 9.--continued.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						%				
25	1	0	1.6	400	1	60	52	34	15	7
26	28	0	1.6	400	1	53	54	61	35	10
27	1	56	1.6	400	2	57	83	94	95	91
28	28	56	1.6	400	2	60	82	94	91	99
29	1	0	8.3	400	1	73	77	78	79	76
30	28	0	8.3	400	1	53	58	71	77	70
31	1	56	8.3	400	2	56	85	92	96	100
32	28	56	8.3	400	2	56	83	90	94	100
33	1	28	5.0	200	1	40	69	81	80	71
34	28	28	5.0	200	1	56	64	60	61	68
35	14	0	5.0	200	1	53	63	74	62	81
36	14	56	5.0	200	1	63	77	84	99	100
37	14	28	1.6	200	1	60	55	58	52	29
38	14	28	8.3	200	1	50	67	73	75	63
39	14	28	5.0	0	1	56	62	74	66	76
40	14	28	5.0	400	1	76	67	79	81	80
41	14	28	5.0	200	3	55	72	74	62	73

†D/G = days grazing, D/R = days rest, G/P = grazing pressure, and F = fertilizer rate.
‡W/S = wet season, D/S = dry season.

the percentage grass tended to increase as the length of rest period increased and to decrease as the grazing pressure increased. The analysis of variance is presented in Appendix Table 37.

For the wet season of 1979, the percentage grass varied from 34 to 96%. Again the length of the rest period (X_2) and grazing pressure (X_3) affected the percentage grass ($P < 0.01$) and there were also significant interactions for $X_1 \times X_3$ and $X_2 \times X_3$ ($P < 0.01$). The linear components of the model accounted for 61% of the total variation, while the quadratic and interaction effects represented 2 and 20% of the total variation, respectively (Appendix Table 38). Again, the percentage grass tended to increase as the length of the rest period increased, while increases in grazing pressure tended to reduce the percentage grass. The analysis of variance is presented in Appendix Table 38.

During the dry season of 1979, the spread in the percentage grass has now increased from 15 to 99%. The days rest (X_2) and grazing pressure (X_3) were even more evident during the fourth season and there were also significant interactions between $X_2 \times X_3$ ($P < 0.01$). The effect upon percentage grass of days grazing and fertilizer level were nil.

The linear components of the model in the dry season of 1979 accounted for 68% of the total variation, while the quadratic and interaction effects represented 1 and 17%, respectively (Appendix Table 39). Again the percentage grass tended to increase as the length of rest period increased, and to decrease as the grazing pressure was increased.

During the wet season of 1980, which was the final season of the experiment, the percentage grass ranged from 7 to 100%. The linear and quadratic effects of days rest (X_2) and grazing pressure (X_3) were very evident ($P < 0.01$) and there was also a strong interaction between $X_2 \times X_3$. Again days grazing (X_1) and level of fertilizer (X_4) had no effect. The linear components of the model accounted for 64% of the total variation, while the quadratic and interaction effects represented 7 and 19%, respectively (Appendix Table 40).

Visual estimation of percentage grass was recorded on the same dates that grass yields were taken. Some rather drastic changes occurred over time and the effects of treatments from the beginning of the experiment through the last grazing season are summarized below.

During the first wet season (May-June) of 1978, no effects of treatments were recorded, whereas in the last wet season of 1980, both linear and quadratic effects ($P < 0.01$) of days rest (X_2) and grazing pressure (X_3) as well as a significant interaction between $X_2 \times X_3$ were very evident. While it is not certain that two years are sufficient to produce stable associations, it is clear that both grasses (elephantgrass and Guineagrass) are very responsive to days rest and to grazing pressure. The relationship of these two experimental variables is obviously curvilinear (see Figs. 15, 16, and 17). Low rest periods resulted in swards with 100% grass, whereas these tall-growing grasses almost eliminated under continuous, intensive grazing. Each of these species has a high growth capacity and the ability to

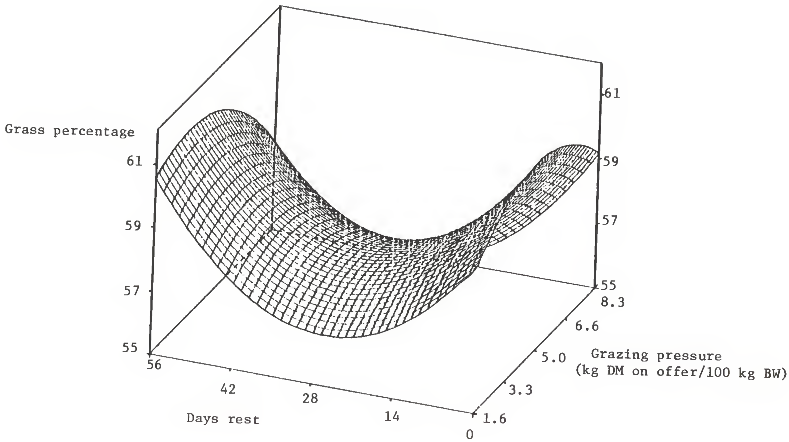

Fig. 15. Effect of rest period and grazing pressure upon grass percentage for the wet season of 1978.

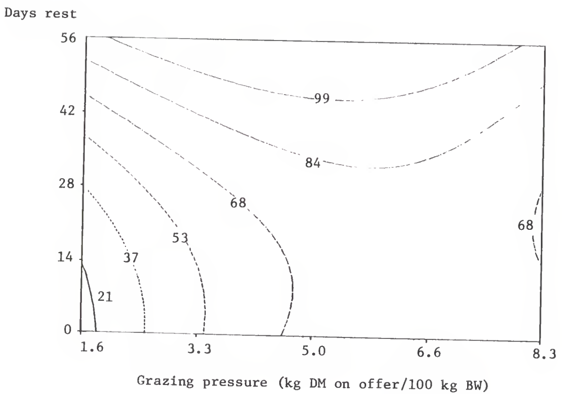

Fig. 16. Contours of grass percentage as affected by levels of rest periods and levels of grazing pressure in the wet season of 1980.

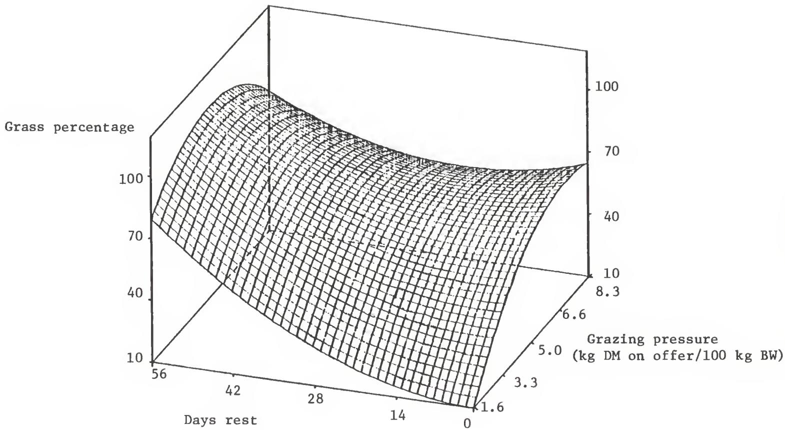

Fig. 17. Effect of rest period and grazing pressure upon grass percentage for the wet season of 1980.

use more efficiently the environmental factors such as light, temperature, moisture, nutrients, and space, producing a highly competitive situation, and finally eliminating the less agressive or unadapted companion species.

The degree of defoliation as represented in this experiment by the intensity of grazing pressure also had a marked effect upon the percentage grass. Again the relationship is quadratic as shown by Figs. 15, 17, and 18.

Harris (1978) mentioned that close, continuous defoliation leads to a more species-rich association dominated by species with prostrate, rhizomatous, stoloniferous or basal rosette habit, while tall species tend to disappear. The dominance or suppression of tall-growing species could largely be controlled by the degree of defoliation permitting or not permitting light penetration to levels where prostrate species dispose their leaf canopies.

The percentage grass at the beginning of the experiment was about 60%, while during the last wet season (1980), the mean percentage grass was 79% which included a spread of from 7 to 100% grass, depending upon the treatment combination. Low grazing pressure in combination with long rest periods produced swards with almost 100% grass, whereas combinations of high grazing pressure and short rest periods or continuous grazing resulted in almost a complete elimination of the grass component. These results were obtained notwithstanding that it is well known that these two species are very well adapted to the environmental conditions of the region.

It is also of interest to note that the experimental variables included in the model accounted for over 90% of the total variability in the percentage of grass in the mixture.

Visual Estimation of Percentage Legume

The visual estimate of percentage of legumes in the mixture is found in Table 10 for each treatment combination and for the five seasons during which this experiment was conducted.

For the first experimental season (May-June of 1978), no significant effects due to the treatments were found. The analysis of variance is presented in Appendix Table 41. As expected, the second order model accounted for only about 12% of the total variability in percentage legume.

During the dry season of 1978, the percentage legume varied from 10 to 45%. Linear effects of days grazing (X_1) ($P < 0.05$) and days rest (X_2) and grazing pressure (X_3) ($P < 0.01$) began to appear in the percentage legume. The effect of X_4 was nil and no interactions among the experimental variables were found. The linear components of the model accounted for 62% of the total variation, while the quadratic and interaction effects represented 1 and 5%, respectively (Appendix Table 42).

The percentage legume tended to increase with increasing length of grazing period while a negative relationship was observed as the length of the rest period increased. The percentage legume also decreased as the grazing pressure decreased. The analysis of variance is presented in Appendix Table 42.

Table 10. Visual estimation of dry matter legume percent for year, season, and treatment combinations.

	Treatments					1978	1978	1979	1979	1980
No.	D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	W/S‡	D/S‡	W/S‡	D/S‡	W/S‡
						%				
1	7	14	3.3	100	1	33	24	19	18	20
2	21	14	3.3	100	1	18	22	18	15	15
3	7	42	3.3	100	1	46	23	10	30	7
4	21	42	3.3	100	1	25	19	9	14	4
5	7	14	6.6	100	1	21	19	19	13	13
6	21	14	6.6	100	1	46	27	25	31	29
7	7	42	6.6	100	1	43	19	9	6	1
8	21	42	6.6	100	1	30	20	11	9	8
9	7	14	3.3	300	1	36	32	19	30	20
10	21	14	3.3	300	1	27	26	21	25	26
11	7	42	3.3	300	1	40	22	14	16	5
12	21	42	3.3	300	1	43	20	12	9	2
13	7	14	6.6	300	1	36	27	19	28	24
14	21	14	6.6	300	1	40	30	32	30	25
15	7	42	6.6	300	1	43	30	9	11	11
16	21	42	6.6	300	1	42	20	6	7	0
17	1	0	1.6	0	1	38	36	23	18	16
18	28	0	1.6	0	1	32	38	28	26	18
19	1	56	1.6	0	2	38	17	5	3	0
20	28	56	1.6	0	2	32	23	9	8	0
21	1	0	8.3	0	1	36	28	18	16	8
22	28	0	8.3	0	1	40	32	15	11	3
23	1	56	8.3	0	2	29	10	3	2	1
24	28	56	8.3	0	2	42	23	21	9	2

Table 10.--continued.

No.	Treatments D/G† (X_1)	D/R† (X_2)	G/P† (X_3) % BW	F† kg ha^{-1}	Reps	1978 W/S‡	1978 D/S‡	1979 W/S‡	1979 D/S‡	1980 W/S‡
						%				
25	1	0	1.6	400	1	33	41	34	9	9
26	28	0	1.6	400	1	38	45	24	43	13
27	1	56	1.6	400	2	35	17	5	3	2
28	28	56	1.6	400	2	40	18	6	9	1
29	1	0	8.3	400	1	22	26	21	19	18
30	28	0	8.3	400	1	40	38	26	21	26
31	1	56	8.3	400	2	38	14	7	3	0
32	28	56	8.3	400	2	40	17	9	6	0
33	1	28	5.0	200	1	53	28	17	18	26
34	28	28	5.0	200	1	33	29	28	30	25
35	14	0	5.0	200	1	43	36	24	37	18
36	14	56	5.0	200	1	36	21	14	0	0
37	14	28	1.6	200	1	33	29	30	27	30
38	14	28	8.3	200	1	36	26	23	23	32
39	14	28	5.0	0	1	43	38	21	33	22
40	14	28	5.0	400	1	21	31	20	19	17
41	14	28	5.0	200	3	37	25	24	21	23

†D/G = days grazing, D/R = days rest, G/P = grazing pressure, and F = fertilizer rate.
‡W/S = wet season, D/S = dry season.

During the wet season of 1979, the percentage of legume varied from 3 to 34%. The linear effect of days rest (X_2) and for the interaction of X_2 x X_3 was significant. There were no direct effects of days grazing (X_1), grazing pressure (X_3), and fertilizer level (X_4). The linear components of the model accounted for 61% of the total variation, while the quadratic and interaction effects represented 4 and 9% of the total variation, respectively (Appendix Table 43). Again the percentage of legume tended to decrease with increasing lengths of rest period.

During the dry season of 1979, the percentage legume varied from 2 to 43%. The number of days grazing (X_1) had a linear effect ($P < 0.05$) upon the percentage legume and the length of the rest period (X_2) also had an effect upon percentage legume ($P < 0.01$). The experimental variables X_3 and X_4 had no effect and there were no interactions among the experimental variables. The linear components of the model accounted for 48% of the total variation, while the quadratic and interaction effects represented 16 and 3% of the total variation, respectively (Appendix Table 44). Again the legume percentage tended to increase with increasing lengths of grazing period while the reverse was true for increasing lengths of rest period.

During the wet season of 1980, the percentage legume had begun to stabilize and varied from 0 to 32%. The length of rest period (X_2) showed both a strong linear and quadratic effect upon the percentage legume in the mixture. There appeared to be little effect of days grazing (X_1), grazing pressure (X_3), and fertility level (X_4)

upon percentage legume. No interactions among the experimental variables were observed. The linear and quadratic components of the model accounted for 46 and 27% of the total variation, respectively, while the interaction effects represented only 2% (Appendix Table 45).

The percentage of legume tended to decrease up to a certain length of rest period and then increased again. The analysis of variance is presented in Appendix Table 45.

A summary of the effects of the experimental variables upon percentage legume is discussed below.

The overall percentage of legume in the mixtures decreased with time but the effect of the experimental variables appeared to reach some stability by the end of the fifth grazing period. The experimental variable having the greatest effect upon the percentage legume was the length of rest period (X_2) if we examine the trends from the wet season of 1978 through the wet season of 1980.

During the wet season of 1980, it is clearly evident that the length of rest period is the factor most influential in determining the percentage legume. The highest percentage legume appears to occur during rest periods of 14 to 28 days and under moderate conditions of grazing pressure. Both extremely short or long rest periods were highly detrimental to the legume population with the greatest destruction occurring for rest periods of 42 days or more. This situation can probably best be explained by the aggressiveness of both of the companion grasses especially during the wet season when the environmental conditions were more favorable for maximum grass

growth. Rest periods of 28 days appeared to be most appropriate for grass-legume yield and balance because the higher values for legume percentage at the end of the wet season of 1980 were recorded on pastures with 28 days rest followed by those which had a rest period of 14 days or continuous grazing. Pastures with 42 or 56 days rest showed zero or very low legume percentages. These results are somewhat contrary to those found by Maraschin (1975) and Serrao (1976) who reported that Desmodium intortum increased with the length of rest period when grown in association with Cynodon dactylon. The results obtained by these authors can probably be explained by the fact that the competitive grass is a low-growing species which did not have nearly the destructive effect upon the associated legume. Zapata (1981) and INIAP (1980) reported that guineagrass-glycine pastures with more than six years maintained an acceptable balance of both species with 25% or more of legume when these pastures were subjected to a rotational grazing system of 28 days grazing and 28 days rest.

In this experiment, the percentage legume was also responsive to length of grazing ($P < 0.05$) for the dry season of 1978 and the wet and dry season of 1979, but this effect disappeared during the last season of 1980. Both of the legumes in this study, centro and glycine, tended to increase as the length of grazing was increased especially under the continuous grazing where due to frequent defoliation, the grass-legume percentage was more stable but declined during the entire course of the experiment.

Grazing pressure appeared as a significant factor ($P < 0.01$) only during the dry season of 1978 where legume percentage was more responsive to higher levels of grazing pressure. While the grazing pressure decreased, the legume percentage also showed a declining trend. During the remaining four seasons of the experiment, no significant effects of this variable were observed.

The effects of rest period (X_2) and grazing pressure (X_3) on legume percentage is presented in Figs. 18 and 20 for the wet season of 1978 and the wet season of 1980, respectively. The contours of the response surface of percentage legume appears in Fig. 19 for the wet season of 1980.

Percentage legume appears to be always higher than the actual legume yield. This may be explained by the plants growth habit, distribution on the soil surface and upon the associated grases, and finally by their morphological characteristics (broadleaves) which leads the observer to overestimate the actual percentage of tropical legumes. This is evident if we compare the response surfaces for legume yield and percentage legume in Figs. 11 and 20.

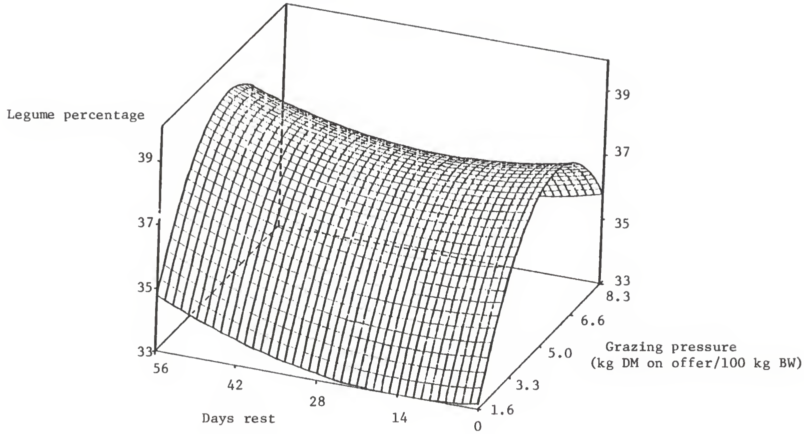

Fig. 18. Effect of rest period and grazing pressure upon legume percentage for the wet season of 1978.

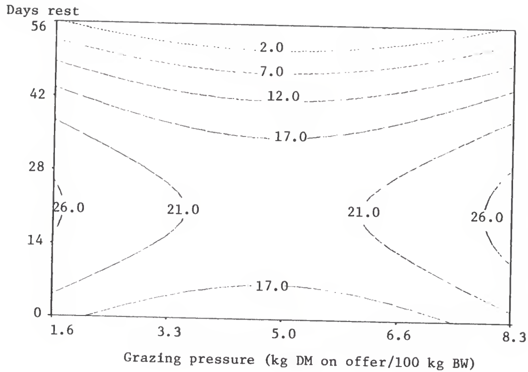

Fig. 19. Contours of legume percentage as affected by length of rest period and levels of grazing pressure in the wet season of 1980.

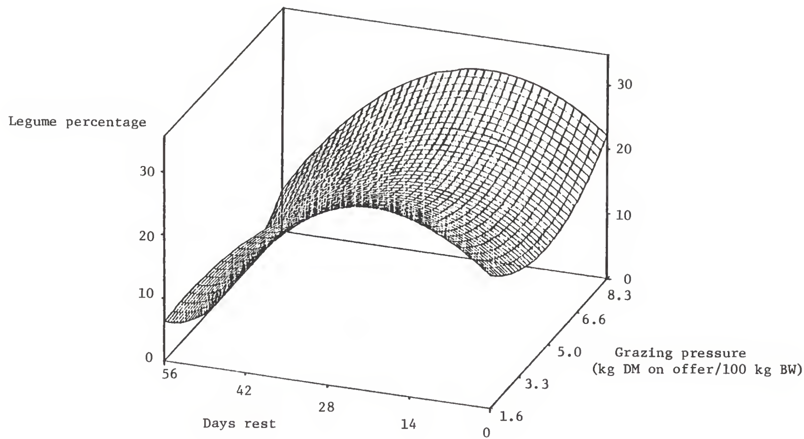

Fig. 20. Effect of rest period and grazing pressure upon legume percentage for the wet season of 1980.

CHAPTER V
SUMMARY AND CONCLUSIONS

A grazing trial was conducted at the Estacion Experimental Tropical Pichilingue, belonging to Instituto Nacional de Investigaciones Agropecuarias (INIAP) and located 7 km from Canton Quevedo, at 1° 06' S Lat. and 79° 21' W Long. The soil is classified as Torripsamments. The experiment covered an area of 7.3 ha, which was subdivided into 51 individual pastures, each large enough to be grazed by at least one animal during the designated grazing period. Pasture sizes ranged from 500 to 4000 m^2; the larger area provided for the continuous grazing treatments.

Land preparation for the experimental area began in May of 1977, after existing vegetation was eliminated and plowed under. In early October of the same year, a mixture of glycine and centro was sown at the rates of 3.0 and 6.0 kg ha^{-1} in rows spaced 1.4 m apart. Two weeks later guineagrass and elephantgrass were planted vegetatively between the rows of the legumes.

Four experimental variables were studied at each of five levels, namely, days grazing: 1, 7, 14, 21, and 28 days; days rest: 0, 14, 28, 42, and 56 days; grazing pressure: 1.6, 3.3, 5.0, 6.6, and 8.3 kg dry matter on offer/100 kg BW; and levels of phosphorus fertilization: 0, 100, 200, 300, and 400 kg ha^{-1} of superphosphate.

A modified non-rotatable central composite response surface design was used which included 41 selected treatment combinations. Certain treatments were replicated which accounted for the 51 experimental units.

The collection of data started in May 1978 and ended in June 1980. Aerial biomass (DM), available forage (DM), grass yield (DM), legume yield (DM), yield of weeds (DM), grass percentage and legume percentage were estimated for each grazing cycle by a double-sampling procedure. During the first 3 1/2 months, 15 random observations of one m^2 each were taken with a forage disk meter. From these sampling units three were randomly selected and clipped at ground level for actual yield determinations (DM) and percent composition. From September 1978 the number of samples taken was increased to 30 units of the same size and five sampling units out of the 30 were randomly selected and clipped for the above determinations. These samples were later hand separated into their components and dried for 20 hours. The sum of the dry weights of the components yielded the total dry weight of the sample. These values were used for aerial biomass (DM), available forage (DM), and for the individual component yields (DM). Estimations for growth during grazing were made to achieve the total available forage (DM).

Visual estimates of botanical composition were also taken in order to determine the amount of the individual components in terms of percentage. The visual estimate of percent yield was made for the components grasses, legumes, and weeds.

From the results of this experiment based on the information obtained from the responses which were measured, the following conclusions appear to be justified.

Aerial biomass (DM) and available forage (DM) were increased as the rest periods increased and grazing pressure decreased (forage

dry matter on offer was increased). No interactions between these two factors were found, suggesting that longer rest periods and lower grazing pressures independently were required to maintain high dry matter production.

Grass (DM) yield and grass percentage appeared to be highly sensitive to short rest periods and high grazing pressures. The negative influence of increased grazing pressure upon the grass component was partially offset by increasing the rest periods.

Legume (DM) yields and legume percentages were highly sensitive to lengths of rest period and less sensitive to high grazing pressures. Short rest periods favored legume content, but its greatest contribution appeared to be near the middle range of rest periods. This response apparently is independent of length of grazing period.

Legume (DM) yield and legume percentage showed a slight decline during the five experimental seasons, while grass yield (DM) and grass percentage increased during the same period of time.

The weed component was reduced by long rest periods and by low grazing pressures. Interactions occurred between these two variables. Both high grazing pressures and short rest periods were responsible for increasing the yield of weeds (DM). The results of this study suggest that a grazing management system which combines a moderate rest period and a moderate level of grazing pressure would be an optimum management strategy to maintain a low amount of weeds, a large amount of legumes and high yields of available forage. The other two variables, days grazing and levels of phosphorus fertilization had negligible effects upon the response of the pasture sward.

APPENDIX

Table 11. Analysis of variance, regression coefficients and probabilities for aerial biomass (g DM/m^2) for the wet season of 1978.

RESPONSE MEAN	252.2075
ROOT MSE	72.0626
R-SQUARE	0.38071262
COEF OF VARIATION	0.28889736

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	64066.7074	0.2076	3.02	0.0303
QUADRATIC	4	12387.0554	0.0401	0.58	0.6766
CROSSPRODUCT	6	41038.5274	0.1330	1.29	0.2873
TOTAL REGRESS	14	117494	0.3807	1.58	0.1327

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	70362.4838	2706.2494	0.224	0.9990
PURE ERROR	10	120760	12075.9974		
TOTAL ERROR	36	191122	5308.9572		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	232.2371	18.4280	12.60	0.0001
X1	1	-0.23004738	6.9548	-0.03	0.9738
X2	1	19.7808	6.9645	2.84	0.0074
X3	1	8.1615	6.9548	1.17	0.2483
X4	1	-2.2753	6.9548	-0.33	0.7433
X1*X1	1	-6.5096	11.2784	-0.58	0.5627
X1*X2	1	-0.02465075	3.8093	-0.01	0.9949
X2*X2	1	14.3687	11.2784	1.27	0.2108
X1*X3	1	5.4710	3.6431	1.50	0.1419
X2*X3	1	2.0349	3.8093	0.53	0.5965
X3*X3	1	-3.7979	11.2784	-0.34	0.7383
X1*X4	1	7.1714	3.6431	1.97	0.0561
X2*X4	1	-4.2617	3.8093	-1.12	0.2706
X3*X4	1	0.74020833	3.6431	0.20	0.8401
X4*X4	1	1.8687	11.2784	0.17	0.8693

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	34478.0823	6895.7765	1.30	0.2861
X2	5	60902.9158	12180.5832	2.29	0.0657
X3	5	24569.4311	4913.8862	0.93	0.4758
X4	5	30200.4168	6040.0834	1.14	0.3584

Table 12. Analysis of variance, regression coefficients and probabilities for aerial biomass (g DM/m^2) for the dry season of 1978.

RESPONSE MEAN	304.9018
ROOT MSE	71.9100
R-SQUARE	0.76482082
COEF OF VARIATION	0.23584627

REGRESSION	DF	TYPE 1 SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	582507	0.7359	28.16	0.0001
QUADRATIC	4	8183.1417	0.0103	0.40	0.8104
CROSSPRODUCT	6	14735.0435	0.0186	0.47	0.8224
TOTAL REGRESS	14	605425	0.7648	8.36	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	82791.6925	3184.2959	0.308	0.9924
PURE ERROR	10	103366	10336.5794		
TOTAL ERROR	36	186157	5171.0413		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	274.4606	18.1871	15.09	0.0001
X1	1	-2.5948	6.8638	-0.38	0.7076
X2	1	43.1704	6.8735	6.28	0.0001
X3	1	50.7477	6.8638	7.39	0.0001
X4	1	-12.9720	6.8638	-1.89	0.0664
X1*X1	1	3.6619	11.1310	0.33	0.7441
X1*X2	1	-0.07950613	3.7595	-0.02	0.9832
X2*X2	1	7.3209	11.1310	0.66	0.5149
X1*X3	1	4.4033	3.5955	1.22	0.2287
X2*X3	1	3.5380	3.7595	0.74	0.3529
X3*X3	1	-1.0006	11.1310	-0.09	0.9289
X1*X4	1	0.56158148	3.5955	0.16	0.8768
X2*X4	1	1.2143	3.7595	0.32	0.7486
X3*X4	1	-2.0808	3.5955	-0.58	0.5664
X4*X4	1	-2.8006	11.1310	-0.25	0.8028

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	9278.2281	1855.6456	0.36	0.8731
X2	5	212945	42589.0883	8.24	0.0001
X3	5	346557	69311.4215	13.40	0.0001
X4	5	21010.6802	4202.1360	0.81	0.5485

Table 13. Analysis of variance, regression coefficients and probabilities for aerial biomass (g DM/m^2) for the wet season of 1979.

RESPONSE MEAN	403.2542
ROOT MSE	104.5726
R-SQUARE	0.70358547
COEF OF VARIATION	0.25732185

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	885040	0.6664	20.23	0.0001
QUADRATIC	4	30205.4997	0.0227	0.69	0.6033
CROSSPRODUCT	6	19204.3230	0.0145	0.29	0.9365
TOTAL REGRESS	14	934450	0.7036	6.10	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	186479	7172.2821	0.346	0.9856
PURE ERROR	10	207196	20719.6250		
TOTAL ERROR	36	393676	10935.4329		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	345.3054	26.4479	13.06	0.0001
X1	1	-6.0460	9.9815	-0.61	0.5485
X2	1	69.6999	9.9955	6.97	0.0001
X3	1	46.0868	9.9815	4.62	0.0001
X4	1	-5.8089	9.9815	-0.58	0.5642
X1*X1	1	6.9550	16.1868	0.43	0.6700
X1*X2	1	-5.9221	5.4671	-1.08	0.2859
X2*X2	1	2.9841	16.1868	0.18	0.8548
X1*X3	1	0.32452500	5.2286	0.06	0.9509
X2*X3	1	0.06867165	5.4671	0.01	0.9900
X3*X3	1	-2.3971	16.1868	-0.15	0.8831
X1*X4	1	3.0579	5.2286	0.58	0.5623
X2*X4	1	1.1317	5.4671	0.21	0.8372
X3*X4	1	2.3022	5.2286	0.44	0.6623
X4*X4	1	7.7929	16.1868	0.48	0.6331

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	28799.4146	5759.8829	0.53	0.7545
X2	5	546874	109375	10.00	0.0001
X3	5	257688	51537.6265	4.71	0.0021
X4	5	12114.9188	2422.9838	0.22	0.9509

Table 14. Analysis of variance, regression coefficients and probabilities for aerial biomass (g DM/m^2) for the dry season of 1979.

RESPONSE MEAN	311.3759
ROOT MSE	97.7679
R-SQUARE	0.53228424
COEF OF VARIATION	0.31396663

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	333107	0.4528	8.71	0.0001
QUADRATIC	4	9693.7000	0.0132	0.25	0.9056
CROSSPRODUCT	6	48811.8681	0.0663	0.85	0.5396
TOTAL REGRESS	14	371613	0.5323	2.93	0.0047

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	199777	7683.7481	0.532	0.9043
PURE ERROR	10	144331	14433.0972		
TOTAL ERROR	36	344108	9558.5673		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	284.5735	24.7269	11.51	0.0001
X1	1	-4.1311	9.3320	-0.44	0.6606
X2	1	23.5222	9.3451	2.52	0.0164
X3	1	47.5909	9.3320	5.10	0.0001
X4	1	-4.9342	9.3320	-0.53	0.6002
X1*X1	1	5.1012	15.1335	0.34	0.7380
X1*X2	1	7.5316	5.1113	1.47	0.1493
X2*X2	1	-3.7788	15.1335	-0.25	0.8032
X1*X3	1	5.6375	4.8884	1.15	0.2564
X2*X3	1	-2.4585	5.1113	-0.48	0.6334
X3*X3	1	3.7075	15.1335	0.24	0.8079
X1*X4	1	4.4289	4.8884	0.91	0.3710
X2*X4	1	1.9631	5.1113	0.38	0.7032
X3*X4	1	3.1137	4.8804	0.64	0.5282
X4*X4	1	3.2533	15.1335	0.21	0.8310

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	42399.9627	8479.9925	0.89	0.4998
X2	5	85209.7709	17041.9982	1.78	0.1412
X3	5	276393	55278.6810	5.78	0.0005
X4	5	15389.0544	3077.8109	0.32	0.8964

Table 15. Analysis of variance, regression coefficients and probabilities for aerial biomass (g DM/m^2) for the wet season of 1980.

RESPONSE MEAN	417.1836
ROOT MSE	147.3207
R-SQUARE	0.52770332
COEF OF VARIATION	0.35313162

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	713398	0.4312	8.22	0.0001
QUADRATIC	4	133039	0.0804	1.53	0.2135
CROSSPRODUCT	6	26824.4504	0.0162	0.21	0.9727
TOTAL REGRESS	14	873262	0.5278	2.87	0.0054

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	519574	19983.6280	0.763	0.7235
PURE ERROR	10	261748	26174.7819		
TOTAL ERROR	36	781322	21703.3927		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	321.7268	37.2595	8.63	0.0001
X1	1	-10.4159	14.0618	-0.74	0.4637
X2	1	55.4276	14.0815	3.94	0.0004
X3	1	45.2128	14.0618	3.22	0.0028
X4	1	-6.7517	14.0618	-0.48	0.6340
X1*X1	1	13.8832	22.8038	0.61	0.5465
X1*X2	1	-3.2825	7.7020	-0.43	0.6725
X2*X2	1	7.3623	22.8038	0.32	0.7487
X1*X3	1	3.7180	7.3660	0.50	0.6168
X2*X3	1	-2.2792	7.7020	-0.30	0.7690
X3*X3	1	5.9623	22.8038	0.26	0.7952
X1*X4	1	4.8870	7.3660	0.66	0.5113
X2*X4	1	-1.1345	7.7020	-0.15	0.8837
X3*X4	1	3.6838	7.3660	0.50	0.6200
X4*X4	1	5.9707	22.8038	0.26	0.7949

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	44832.3549	8966.4710	0.41	0.8365
X2	5	347008	69401.6054	3.20	0.0172
X3	5	246633	49326.5173	2.27	0.0679
X4	5	23434.6732	4686.9346	0.22	0.9534

Table 16. Analysis of variance, regression coefficients and probabilities for available forage (g DM/m^2) for the wet season of 1978.

RESPONSE MEAN	246.0856
ROOT MSE	72.4536
R-SQUARE	0.37994512
COEF OF VARIATION	0.29442454

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	62685.3379	0.2057	2.77	0.0316
QUADRATIC	4	15514.7602	0.0509	0.74	0.5717
CROSSPRODUCT	6	37601.2802	0.1234	1.19	0.3317
TOTAL REGRESS	14	115801	0.3799	1.58	0.1343

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	71515.1042	2750.5807	0.234	0.9986
PURE ERROR	10	117468	11746.8008		
TOTAL ERROR	36	188983	5249.5309		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	225.2208	18.3246	12.29	0.0001
X1	1	-0.92600826	6.9157	-0.13	0.8942
X2	1	19.5255	6.9254	2.82	0.0078
X3	1	7.5467	6.9157	1.09	0.2824
X4	1	-3.2638	6.9157	-0.47	0.6398
X1*X1	1	-7.7256	11.2151	-0.69	0.4953
X1*X2	1	-0.07258868	3.7879	-0.02	0.9848
X2*X2	1	15.8160	11.2151	1.41	0.1671
X1*X3	1	5.0666	3.6227	1.40	0.1705
X2*X3	1	1.4203	3.7879	0.37	0.7099
X3*X3	1	-5.1840	11.2151	-0.46	0.6467
X1*X4	1	6.9822	3.6227	1.93	0.0619
X2*X4	1	-4.4027	3.7879	-1.16	0.2528
X3*X4	1	0.03908333	3.6227	0.01	0.9915
X4*X4	1	3.3577	11.2151	0.30	0.7664

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	32373.4814	6474.6963	1.23	0.3138
X2	5	61408.3773	12281.6755	2.34	0.0614
X3	5	20403.4411	4080.6882	0.78	0.5725
X4	5	30843.0311	6168.6062	1.18	0.3404

Table 17. Analysis of variance, regression coefficients and probabilities for available forage (g DM/m^2) for the dry season of 1978.

RESPONSE MEAN	301.0755
ROOT MSE	72.2359
R-SQUARE	0.76545726
COEF OF VARIATION	0.23992627

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	589779	0.7364	28.26	0.0001
QUADRATIC	4	9468.3109	0.0118	0.45	0.7691
CROSSPRODUCT	6	13826.8157	0.0173	0.44	0.8460
TOTAL REGRESS	14	613074	0.7655	8.39	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	83859.3783	3225.3607	0.310	0.9921
PURE ERROR	10	103990	10398.9630		
TOTAL ERROR	36	187849	5218.0280		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	268.8889	18.2695	14.72	0.0001
X1	1	-2.8808	6.8950	-0.42	0.6786
X2	1	44.1255	6.9046	6.39	0.0001
X3	1	50.4124	6.8950	7.31	0.0001
X4	1	-13.1554	6.8950	-1.91	0.0644
X1*X1	1	2.5463	11.1814	0.23	0.8211
X1*X2	1	0.04082591	3.7765	0.01	0.9914
X2*X2	1	8.4880	11.1814	0.76	0.4527
X1*X3	1	4.1572	3.6118	1.15	0.2573
X2*X3	1	3.4631	3.7765	0.92	0.3652
X3*X3	1	-1.8853	11.1814	-0.17	0.8670
X1*X4	1	0.59127037	3.6118	0.16	0.8709
X2*X4	1	1.2596	3.7765	0.33	0.7407
X3*X4	1	-2.1243	3.6118	-0.59	0.5601
X4*X4	1	-1.3530	11.1814	-0.12	0.9044

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	8304.9583	1660.9917	0.32	0.8987
X2	5	222956	44591.1075	8.55	0.0001
X3	5	340980	68195.9001	13.07	0.0001
X4	5	21302.6361	4260.5272	0.82	0.5459

Table 18. Analysis of variance, regression coefficients and probabilities for available forage (g DM/m^2) for the wet season of 1979.

RESPONSE MEAN	393. 8455
ROOT MSE	104. 1711
R-SQUARE	0. 73064654
COEF OF VARIATION	0. 26449741

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	1006949	0. 6943	23. 20	0. 0001
QUADRATIC	4	30055. 6043	0. 0207	0. 67	0. 6021
CROSSPRODUCT	6	22692. 5744	0. 0156	0. 35	0. 9061
TOTAL REGRESS	14	1059697	0. 7306	6. 78	0. 0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	181696	6988. 2905	0. 334	0. 9880
PURE ERROR	10	208963	20896. 2721		
TOTAL ERROR	36	390658	10851. 6187		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	334. 7751	26. 3464	12. 71	0. 0001
X1	1	-5. 6979	9. 9432	-0. 57	0. 5702
X2	1	74. 7819	9. 9571	7. 51	0. 0001
X3	1	50. 3946	9. 9432	5. 07	0. 0001
X4	1	-4. 4736	9. 9432	-0. 45	0. 6555
X1*X1	1	5. 1526	16. 1247	0. 32	0. 7512
X1*X2	1	-6. 3854	5. 4461	-1. 17	0. 2487
X2*X2	1	4. 8651	16. 1247	0. 30	0. 7646
X1*X3	1	-0. 33773750	5. 2086	-0. 06	0. 9487
X2*X3	1	-2. 1599	5. 4461	-0. 40	0. 6940
X3*X3	1	-3. 6512	16. 1247	-0. 23	0. 8221
X1*X4	1	3. 1430	5. 2086	0. 60	0. 5500
X2*X4	1	0. 76786291	5. 4461	0. 14	0. 8887
X3*X4	1	2. 1536	5. 2086	0. 41	0. 6817
X4*X4	1	8. 7676	16. 1247	0. 54	0. 5900

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	29967. 6100	5973. 5220	0. 55	0. 7355
X2	5	632164	126433	11. 65	0. 0001
X3	5	295145	59028. 9042	5. 44	0. 0008
X4	5	11212. 5205	2242. 5041	0. 21	0. 9575

Table 19. Analysis of variance, regression coefficients and probabilities for available forage (g DM/m^2) for the dry season of 1979.

RESPONSE MEAN	298.8490
ROOT MSE	98.0390
R-SQUARE	0.60677481
COEF OF VARIATION	0.32805537

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	476562	0.5416	12.40	0.0001
QUADRATIC	4	3527.1872	0.0040	0.09	0.9845
CROSSPRODUCT	6	53887.8220	0.0612	0.93	0.4825
TOTAL REGRESS	14	533977	0.6068	3.97	0.0004

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	201300	7742.3085	0.535	0.9027
PURE ERROR	10	144719	14471.9289		
TOTAL ERROR	36	346019	9611.6475		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	278.0788	24.7955	11.22	0.0001
X1	1	0.56256621	9.3577	0.06	0.9524
X2	1	32.8397	9.3710	3.50	0.0012
X3	1	57.1874	9.3579	6.11	0.0001
X4	1	-5.8085	9.3579	-0.62	0.5387
X1*X1	1	3.3742	15.1755	0.22	0.8253
X1*X2	1	4.8603	5.1255	0.95	0.3493
X2*X2	1	-2.3591	15.1755	-0.16	0.8773
X1*X3	1	3.7646	4.9020	0.77	0.4475
X2*X3	1	-7.2502	5.1255	-1.41	0.1658
X3*X3	1	-1.3409	15.1755	-0.09	0.9301
X1*X4	1	5.5716	4.9020	1.14	0.2632
X2*X4	1	2.5185	5.1255	0.49	0.6261
X3*X4	1	3.7439	4.9020	0.76	0.4500
X4*X4	1	4.7659	15.1755	0.31	0.7553

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	28398.1963	5679.6393	0.59	0.7069
X2	5	148251	29650.2621	3.08	0.0203
X3	5	371753	74350.6865	7.74	0.0001
X4	5	23685.1872	4737.0374	0.49	0.7794

Table 20. Analysis of variance, regression coefficients and probabilities for available forage (g DM/m^2) for the wet season of 1980.

RESPONSE MEAN	392.8804
ROOT MSE	145.3508
R-SQUARE	0.64206735
COEF OF VARIATION	0.36995428

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	1201016	0.5652	14.21	0.0001
QUADRATIC	4	68540.3460	0.0323	0.81	0.5264
CROSSPRODUCT	6	94763.7656	0.0446	0.75	0.6153
TOTAL REGRESS	14	1364320	0.6421	4.61	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	504704	19411.6913	0.759	0.7276
PURE ERROR	10	255862	25586.2299		
TOTAL ERROR	36	760566	21126.8409		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	314.6188	36.7613	8.56	0.0001
X1	1	-7.5611	13.8738	-0.54	0.5891
X2	1	76.0399	13.8932	5.47	0.0001
X3	1	64.9473	13.8738	4.68	0.0001
X4	1	-13.9012	13.8738	-1.00	0.3230
X1*X1	1	11.9732	22.4989	0.53	0.5979
X1*X2	1	-4.2700	7.5990	-0.56	0.5777
X2*X2	1	8.8232	22.4989	0.39	0.6973
X1*X3	1	2.9151	7.2675	0.40	0.6907
X2*X3	1	-12.2149	7.5990	-1.61	0.1167
X3*X3	1	-3.9685	22.4989	-0.18	0.8610
X1*X4	1	4.6592	7.2675	0.64	0.5255
X2*X4	1	2.5108	7.5990	0.33	0.7430
X3*X4	1	6.9129	7.2675	0.95	0.3478
X4*X4	1	6.2982	22.4989	0.28	0.7811

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	36351.6503	7270.3301	0.34	0.8826
X2	5	703288	140658	6.66	0.0002
X3	5	487486	97497.2963	4.61	0.0023
X4	5	50697.4944	10139.4989	0.48	0.7888

Table 21. Analysis of variance, regression coefficients and probabilities for grass yield (g DM/m^2) for the wet season of 1978.

RESPONSE MEAN	153.3261
ROOT MSE	62.4835
R-SQUARE	0.32632870
COEF OF VARIATION	0.40751797

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	30758.8278	0.1474	1.97	0.1201
QUADRATIC	4	11826.1364	0.0567	0.76	0.5599
CROSSPRODUCT	6	25498.2358	0.1222	1.09	0.3878
TOTAL REGRESS	14	68083.2000	0.3263	1.25	0.2874

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	42242.3904	1624.7073	0.165	1.0000
PURE ERROR	10	78308.2164	9830.8216		
TOTAL ERROR	36	140551	3904.1835		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	133.4364	15.8030	8.44	0.0001
X1	1	-0.81542760	5.9641	-0.14	0.8920
X2	1	12.8698	5.9724	2.15	0.0379
X3	1	3.7329	5.9641	0.63	0.5353
X4	1	-4.1201	5.9641	-0.69	0.4941
X1*X1	1	-8.2324	9.6718	-0.85	0.4003
X1*X2	1	-0.68669825	3.2667	-0.21	0.8347
X2*X2	1	9.8510	9.6718	1.02	0.3152
X1*X3	1	3.5747	3.1242	1.15	0.2575
X2*X3	1	1.4299	3.2667	0.44	0.6642
X3*X3	1	-1.5240	9.6718	-0.16	0.8757
X1*X4	1	5.7803	3.1242	1.85	0.0725
X2*X4	1	-3.4696	3.2667	-1.06	0.2952
X3*X4	1	2.0247	3.1242	0.65	0.5211
X4*X4	1	6.6426	9.6718	0.69	0.4966

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	21702.1795	4340.4359	1.11	0.3714
X2	5	28082.6822	5616.5364	1.44	0.2342
X3	5	10078.5555	2015.7111	0.52	0.7622
X4	5	25528.2979	5105.6596	1.31	0.2825

Table 22. Analysis of variance, regression coefficients and probabilities for grass yield (g DM/m^2) for the dry season of 1978.

RESPONSE MEAN	236.9873
ROOT MSE	65.4161
R-SQUARE	0.77736794
COEF OF VARIATION	0.27603208

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	512740	0.7410	29.95	0.0001
QUADRATIC	4	14080.7664	0.0203	0.82	0.5194
CROSSPRODUCT	6	11090.4024	0.0160	0.43	0.8527
TOTAL REGRESS	14	537911	0.7774	8.98	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	66229.4086	2547.2849	0.290	0.9946
PURE ERROR	10	87824.1534	8782.4153		
TOTAL ERROR	36	154054	4279.2656		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	200.2190	16.5447	12.10	0.0001
X1	1	-5.7008	6.2440	-0.91	0.3673
X2	1	44.4427	6.2527	7.11	0.0001
X3	1	43.1947	6.2440	6.92	0.0001
X4	1	-10.6236	6.2440	-1.70	0.0975
X1*X1	1	2.5684	10.1258	0.25	0.8012
X1*X2	1	-0.61524319	3.4200	-0.18	0.8582
X2*X2	1	10.0406	10.1258	0.99	0.3280
X1*X3	1	1.8140	3.2708	0.55	0.5826
X2*X3	1	4.0339	3.4200	1.18	0.2459
X3*X3	1	-1.7452	10.1258	-0.17	0.8641
X1*X4	1	1.8008	3.2708	0.55	0.5853
X2*X4	1	1.7798	3.4200	0.52	0.6060
X3*X4	1	-1.7508	3.2708	-0.54	0.5957
X4*X4	1	-1.1629	10.1258	-0.11	0.9092

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	7388.8802	1477.7760	0.35	0.8818
X2	5	229831	45966.2935	10.74	0.0001
X3	5	255375	51074.9679	11.94	0.0001
X4	5	14969.9691	2993.9938	0.70	0.6273

Table 23. Analysis of variance, regression coefficients and probabilities for grass yield (g DM/m^2) for the wet season of 1979.

RESPONSE MEAN	346.4752
ROOT MSE	96.5948
R-SQUARE	0.77381777
COEF OF VARIATION	0.27879271

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	1067382	0.7187	28.60	0.0001
QUADRATIC	4	47265.5552	0.0318	1.27	0.3011
CROSSPRODUCT	6	34536.8369	0.0233	0.62	0.7153
TOTAL REGRESS	14	1149185	0.7738	8.80	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	170807	6569.5116	0.398	0.9712
PURE ERROR	10	165092	16509.2395		
TOTAL ERROR	36	335900	9330.5471		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	277.3786	24.4302	11.35	0.0001
X1	1	-9.8372	9.2200	-1.07	0.2931
X2	1	80.3952	9.2329	8.71	0.0001
X3	1	43.8425	9.2200	4.76	0.0001
X4	1	-5.7958	9.2200	-0.63	0.5336
X1*X1	1	4.6445	14.9519	0.31	0.7579
X1*X2	1	-7.5150	5.0500	-1.49	0.1454
X2*X2	1	8.3716	14.9519	0.56	0.5790
X1*X3	1	-2.4081	4.8297	-0.50	0.6211
X2*X3	1	-2.4641	5.0500	-0.49	0.6286
X3*X3	1	-6.0409	14.9519	-0.40	0.6886
X1*X4	1	4.1761	4.8297	0.86	0.3929
X2*X4	1	1.3914	5.0500	0.28	0.7845
X3*X4	1	2.0305	4.8297	0.42	0.6767
X4*X4	1	11.6716	14.9519	0.78	0.4401

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	53860.9942	10772.1988	1.15	0.3502
X2	5	737651	147530	15.81	0.0001
X3	5	224753	44950.5041	4.82	0.0018
X4	5	18083.8137	3616.7627	0.39	0.8540

Table 24. Analysis of variance, regression coefficients and probabilities for grass yield (g DM/m^2) for the dry season of 1979.

RESPONSE MEAN	259.1133
ROOT MSE	98.4460
R-SQUARE	0.64076954
COEF OF VARIATION	0.37993430

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	552655	0.5690	14.26	0.0001
QUADRATIC	4	20881.1498	0.0215	0.54	0.7083
CROSSPRODUCT	6	48803.8361	0.0502	0.84	0.5480
TOTAL REGRESS	14	622340	0.6408	4.59	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	201849	7763.4236	0.528	0.9072
PURE ERROR	10	147049	14704.9388		
TOTAL ERROR	36	348098	9691.6223		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	215.6553	24.8984	8.66	0.0001
X1	1	-1.0988	9.3967	-0.12	0.9076
X2	1	42.5550	9.4099	4.52	0.0001
X3	1	54.0557	9.3967	5.75	0.0001
X4	1	-5.8094	9.3967	-0.62	0.5403
X1*X1	1	3.5619	15.2385	0.23	0.8165
X1*X2	1	4.3560	5.1468	0.85	0.4029
X2*X2	1	6.6578	15.2385	0.44	0.6648
X1*X3	1	4.2282	4.9223	0.86	0.3960
X2*X3	1	-5.6522	5.1468	-1.10	0.2794
X3*X3	1	-1.9652	15.2385	-0.13	0.8981
X1*X4	1	5.8277	4.9223	1.18	0.2442
X2*X4	1	3.3516	5.1468	0.65	0.5191
X3*X4	1	3.6495	4.9223	0.74	0.4632
X4*X4	1	4.5411	15.2385	0.30	0.7674

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	28387.3765	5677.4753	0.59	0.7107
X2	5	224254	44850.7307	4.63	0.0023
X3	5	336953	67390.5397	6.95	0.0001
X4	5	25823.9396	5164.7879	0.53	0.7499

Table 25. Analysis of variance, regression coefficients and probabilities for grass yield (g DM/m^2) for the wet season of 1980.

RESPONSE MEAN		363.4776			
ROOT MSE		147.0421			
R-SQUARE		0.67586055			
COEF OF VARIATION		0.40454239			

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	1424838	0.5933	16.47	0.0001
QUADRATIC	4	121867	0.0507	1.41	0.2506
CROSSPRODUCT	6	76325.8509	0.0318	0.59	0.7373
TOTAL REGRESS	14	1623031	0.6759	5.36	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	524564	20175.5288	0.795	0.6968
PURE ERROR	10	253806	25380.5708		
TOTAL ERROR	36	778369	21621.3738		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	264.8106	37.1891	7.12	0.0001
X1	1	-8.5992	14.0352	-0.61	0.5439
X2	1	87.0574	14.0549	6.19	0.0001
X3	1	61.2220	14.0352	4.36	0.0001
X4	1	-16.3700	14.0352	-1.17	0.2511
X1*X1	1	8.6804	22.7607	0.38	0.7052
X1*X2	1	-3.8556	7.6874	-0.50	0.6190
X2*X2	1	19.6096	22.7607	0.86	0.3946
X1*X3	1	2.8014	7.3521	0.38	0.7054
X2*X3	1	-10.5737	7.6874	-1.38	0.1775
X3*X3	1	-7.3154	22.7607	-0.32	0.7498
X1*X4	1	4.1419	7.3521	0.56	0.5767
X2*X4	1	3.9082	7.6874	0.52	0.6071
X3*X4	1	5.9500	7.3521	0.81	0.4237
X4*X4	1	9.3512	22.7607	0.41	0.6836

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	32209.8692	6441.9738	0.30	0.9108
X2	5	906124	181225	8.38	0.0001
X3	5	431172	86234.3239	3.99	0.0056
X4	5	54835.6907	10967.1381	0.51	0.7688

Table 26. Analysis of variance, regression coefficients and probabilities for legume yield (g DM/m^2) for the wet season of 1978.

RESPONSE MEAN	92.7595
ROOT MSE	28.2070
R-SQUARE	0.29723352
COEF OF VARIATION	0.30400795

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	6690.6737	0.1642	2.10	0.1007
QUADRATIC	4	1945.7639	0.0477	0.61	0.6571
CROSSPRODUCT	6	3478.0272	0.0853	0.73	0.6296
TOTAL REGRESS	14	12114.4649	0.2972	1.09	0.4000

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	20127.0462	774.1172	0.709	0.6019
PURE ERROR	10	8515.8074	851.5887		
TOTAL ERROR	36	28642.9336	795.6370		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	91.7844	7.1340	12.87	0.0001
X1	1	-0.11058066	2.6924	-0.04	0.9675
X2	1	6.6558	2.6961	2.47	0.0184
X3	1	3.8137	2.6924	1.42	0.1652
X4	1	0.85625607	2.6924	0.32	0.7523
X1*X1	1	0.50674037	4.3662	0.12	0.9082
X1*X2	1	0.61410957	1.4747	0.42	0.6796
X2*X2	1	5.9651	4.3662	1.37	0.1803
X1*X3	1	1.4719	1.4104	1.04	0.3036
X2*X3	1	-0.00961492	1.4747	-0.01	0.9948
X3*X3	1	-3.6579	4.3662	-0.84	0.4074
X1*X4	1	1.2019	1.4104	0.85	0.3997
X2*X4	1	-0.93308431	1.4747	-0.63	0.5309
X3*X4	1	-1.9856	1.4104	-1.41	0.1677
X4*X4	1	-3.2849	4.3662	-0.75	0.4567

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	1598.8015	319.7603	0.40	0.8443
X2	5	6970.8828	1394.1766	1.75	0.1478
X3	5	4743.3862	948.6772	1.19	0.3323
X4	5	2939.1946	587.8309	0.74	0.5994

Table 27. Analysis of variance, regression coefficients and probabilities for legume yield (g DM/m^2) for the dry season of 1978.

RESPONSE MEAN	64.0882
ROOT MSE	19.5789
R-SQUARE	0.45776632
COEF OF VARIATION	0.30547855

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	7953.3839	0.3125	5.19	0.0021
QUADRATIC	4	483.9329	0.0190	0.32	0.8657
CROSSPRODUCT	6	3212.9068	0.1262	1.40	0.2426
TOTAL REGRESS	14	11650.2236	0.4578	2.17	0.0308

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	6746.5079	259.4811	0.368	0.9803
PURE ERROR	10	7053.4233	705.3423		
TOTAL ERROR	36	13799.9312	383.3314		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	68.6699	4.9518	13.87	0.0001
X1	1	2.8200	1.8688	1.51	0.1400
X2	1	-0.31717234	1.8714	-0.17	0.8664
X3	1	7.2177	1.8688	3.86	0.0005
X4	1	-2.5317	1.8688	-1.35	0.1839
X1*X1	1	-0.02206417	3.0306	-0.01	0.9942
X1*X2	1	0.65606910	1.0236	0.64	0.5256
X2*X2	1	-1.5526	3.0306	-0.51	0.6116
X1*X3	1	2.3432	0.97894257	2.39	0.0220
X2*X3	1	-0.57078768	1.0236	-0.56	0.5805
X3*X3	1	-0.14011772	3.0306	-0.05	0.9634
X1*X4	1	-1.2095	0.97894257	-1.24	0.2246
X2*X4	1	-0.52022254	1.0236	-0.51	0.6144
X3*X4	1	-0.37347176	0.97894257	-0.38	0.7051
X4*X4	1	-0.19011972	3.0306	-0.06	0.9503

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	4144.6972	828.9394	2.16	0.0801
X2	5	489.5885	97.9177	0.26	0.9343
X3	5	8107.3546	1621.4709	4.23	0.0040
X4	5	1688.4728	337.6946	0.88	0.5037

Table 28. Analysis of variance, regression coefficients and probabilities for legume yield (g DM/m^2) for the wet season of 1979.

RESPONSE MEAN		47.3703
ROOT MSE		23.1144
R-SQUARE		0.48320832
COEF OF VARIATION		0.48795267

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	12962.1104	0.3483	6.07	0.0008
QUADRATIC	4	2231.4555	0.0600	1.04	0.3981
CROSSPRODUCT	6	2790.5191	0.0750	0.87	0.5259
TOTAL REGRESS	14	17984.0851	0.4832	2.40	0.0172

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	13604.5041	523.2502	0.929	0.5856
PURE ERROR	10	5629.4893	562.9489		
TOTAL ERROR	36	19233.9934	534.2776		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	57.3965	5.8460	9.82	0.0001
X1	1	4.1393	2.2063	1.88	0.0688
X2	1	-5.6133	2.2094	-2.54	0.0155
X3	1	6.5521	2.2063	2.97	0.0053
X4	1	1.3222	2.2063	0.60	0.5527
X1*X1	1	0.50807593	3.5779	0.14	0.8879
X1*X2	1	1.1295	1.2084	0.93	0.3562
X2*X2	1	-3.5065	3.5779	-0.98	0.3336
X1*X3	1	2.0704	1.1557	1.79	0.0816
X2*X3	1	0.30411686	1.2084	0.25	0.8027
X3*X3	1	2.3897	3.5779	0.67	0.5084
X1*X4	1	-1.0332	1.1557	-0.89	0.3773
X2*X4	1	-0.62354713	1.2084	-0.52	0.6090
X3*X4	1	0.12312500	1.1557	0.11	0.9157
X4*X4	1	-2.9040	3.5779	-0.81	0.4223

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	5317.1780	1063.4356	1.99	0.1036
X2	5	4695.2836	939.0567	1.76	0.1466
X3	5	7402.6295	1480.5259	2.77	0.0323
X4	5	1044.7816	208.9563	0.39	0.8516

Table 29. Analysis of variance, regression coefficients and probabilities for legume yield (g DM/m^2) for the dry season of 1979.

RESPONSE MEAN		39.7357			
ROOT MSE		16.3974			
R-SQUARE		0.74611206			
COEF OF VARIATION		0.41271244			

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	16647.0788	0.4365	15.47	0.0001
QUADRATIC	4	10408.5734	0.2729	9.68	0.0001
CROSSPRODUCT	6	1396.9917	0.0366	0.87	0.5293
TOTAL REGRESS	14	28452.6838	0.7461	7.56	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	8463.0577	325.5022	2.671	0.0532
PURE ERROR	10	1218.8161	121.8816		
TOTAL ERROR	36	9681.8738	268.9409		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	62.4435	4.1476	15.06	0.0001
X1	1	1.6614	1.5653	1.06	0.2756
X2	1	-9.7153	1.5675	-6.20	0.0001
X3	1	3.1317	1.5653	2.00	0.0530
X4	1	0.00095420	1.5653	0.00	0.9995
X1*X1	1	-0.18768706	2.5385	-0.07	0.9415
X1*X2	1	0.50432611	0.85736754	0.59	0.5601
X2*X2	1	-9.0169	2.5385	-3.55	0.0011
X1*X3	1	-0.46363750	0.81997094	-0.57	0.5753
X2*X3	1	-1.5980	0.85736754	-1.86	0.0705
X3*X3	1	0.62429211	2.5385	0.25	0.8071
X1*X4	1	-0.25604583	0.81997094	-0.31	0.7566
X2*X4	1	-0.83306517	0.85736754	-0.97	0.3377
X3*X4	1	0.09435417	0.81997094	0.12	0.9090
X4*X4	1	0.22481294	2.5385	0.09	0.9299

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	653.8830	130.7766	0.49	0.7842
X2	5	15403.7776	3080.7555	11.46	0.0001
X3	5	1663.5866	332.7173	1.24	0.3122
X4	5	309.3916	61.8783	0.23	0.9469

Table 30. Analysis of variance, regression coefficients and probabilities for legume yields (g DM/m^2) for the wet season of 1980.

RESPONSE MEAN	29.4109
ROOT MSE	17.4281
R-SQUARE	0.74933003
COEF OF VARIATION	0.59257260

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	19844.5450	0.4549	16.33	0.0001
QUADRATIC	4	10512.2713	0.2410	8.65	0.0001
CROSSPRODUCT	6	2329.9597	0.0534	1.28	0.2916
TOTAL REGRESS	14	32686.7769	0.7493	7.69	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	10272.0912	395.0804	5.964	0.0027
PURE ERROR	10	662.4674	66.2467		
TOTAL ERROR	36	10934.5587	303.7377		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	49.8082	4.4078	11.30	0.0001
X1	1	1.0380	1.6635	0.62	0.5366
X2	1	-11.0174	1.6658	-6.61	0.0001
X3	1	3.7253	1.6635	2.24	0.0314
X4	1	2.4687	1.6635	1.48	0.1465
X1*X1	1	3.2927	2.6977	1.22	0.2302
X1*X2	1	-0.41436930	0.91114597	-0.45	0.6520
X2*X2	1	-10.7864	2.6977	-4.00	0.0003
X1*X3	1	0.11367063	0.87140367	0.13	0.8969
X2*X3	1	-1.6412	0.91114597	-1.80	0.0800
X3*X3	1	3.3469	2.6977	1.24	0.2228
X1*X4	1	0.51726190	0.87140367	0.59	0.5565
X2*X4	1	-1.4774	0.91114597	-1.62	0.1136
X3*X4	1	0.96290476	0.87140367	1.11	0.2765
X4*X4	1	-3.0531	2.6977	-1.13	0.2652

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	707.6312	141.5262	0.47	0.7990
X2	5	20528.3677	4105.6735	13.52	0.0001
X3	5	2803.7424	560.7485	1.85	0.1285
X4	5	2004.5285	400.7057	1.32	0.2777

Table 31. Analysis of variance, regression coefficients and probabilities for yield of weeds (g DM/m^2) for the wet season of 1978.

RESPONSE MEAN		6.1219			
ROOT MSE		4.7956			
R-SQUARE		0.54421312			
COEF OF VARIATION		0.78335035			
REGRESSION	**DF**	**TYPE I SS**	**R-SQUARE**	**F-RATIO**	**PROB**
LINEAR	4	302.7852	0.1667	3.29	0.0213
QUADRATIC	4	259.8903	0.1431	2.83	0.0389
CROSSPRODUCT	6	425.8630	0.2344	3.09	0.0153
TOTAL REGRESS	14	988.5385	0.5442	3.07	0.0034
RESIDUAL	**DF**	**SS**	**MEAN SQUARE**	**F-RATIO**	**PROB**
LACK OF FIT	26	655.8601	25.2254	1.466	0.2689
PURE ERROR	10	172.0561	17.2056		
TOTAL ERROR	36	827.9162	22.9977		
PARAMETER	**DF**	**ESTIMATE**	**STD DEV**	**T-RATIO**	**PROB**
INTERCEPT	1	7.0163	1.2129	5.78	0.0001
X1	1	0.69596088	0.45774109	1.52	0.1371
X2	1	0.25523599	0.45838220	0.56	0.5811
X3	1	0.61486273	0.45774109	1.34	0.1876
X4	1	0.96855564	0.45774109	2.12	0.0413
X1*X1	1	1.1360	0.74231076	1.53	0.1347
X1*X2	1	0.04793793	0.25071512	0.19	0.8494
X2*X2	1	-1.4473	0.74231076	-1.95	0.0590
X1*X3	1	0.40445833	0.23977945	1.69	0.1003
X2*X3	1	0.61458030	0.25071512	2.45	0.0192
X3*X3	1	1.3860	0.74231076	1.87	0.0700
X1*X4	1	0.20912500	0.23977945	0.87	0.3889
X2*X4	1	0.14098743	0.25071512	0.56	0.5774
X3*X4	1	0.70112500	0.23977945	2.92	0.0059
X4*X4	1	-1.4890	0.74231076	-2.01	0.0524
FACTOR	**DF**	**SS**	**MEAN SQUARE**	**F-RATIO**	**PROB**
X1	5	200.1056	40.0211	1.74	0.1504
X2	5	239.3380	47.8676	2.08	0.0904
X3	5	587.0646	117.4129	5.11	0.0012
X4	5	444.6547	88.9309	3.87	0.0066

Table 32. Analysis of variance, regression coefficients and probabilities of weeds (g DM/m^2) for the dry season of 1978.

RESPONSE MEAN	3.8263
ROOT MSE	3.9778
R-SQUARE	0.42106917
COEF OF VARIATION	1.0396

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	163.2320	0.1659	2.58	0.0537
QUADRATIC	4	217.6507	0.2212	3.44	0.0177
CROSSPRODUCT	6	33.4224	0.0340	0.35	0.9040
TOTAL REGRESS	14	414.3050	0.4211	1.87	0.0653

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	547.2393	21.0477	9.400	0.0004
PURE ERROR	10	22.3915	2.2391		
TOTAL ERROR	36	569.6308	15.8231		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	5.5717	1.0060	5.54	0.0001
X1	1	0.28596412	0.37968499	0.75	0.4563
X2	1	-0.95512573	0.38021678	-2.51	0.0166
X3	1	0.33527535	0.37968499	0.88	0.3831
X4	1	0.16343659	0.37968499	0.43	0.6694
X1*X1	1	1.1156	0.61572855	1.81	0.0784
X1*X2	1	-0.12033204	0.20796204	-0.58	0.5664
X2*X2	1	-1.1671	0.61572855	-1.90	0.0661
X1*X3	1	0.24603889	0.19889116	1.24	0.2241
X2*X3	1	0.07490039	0.20796204	0.36	0.7208
X3*X3	1	0.88466860	0.61572855	1.44	0.1594
X1*X4	1	-0.02968889	0.19889116	-0.15	0.8822
X2*X4	1	-0.04521097	0.20796204	-0.22	0.8291
X3*X4	1	0.04352222	0.19889116	0.22	0.8280
X4*X4	1	-1.4476	0.61572855	-2.35	0.0243

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	87.7077	17.5415	1.11	0.3730
X2	5	169.8434	33.9687	2.15	0.0820
X3	5	76.5836	15.3167	0.97	0.4503
X4	5	91.6502	18.3300	1.16	0.3484

Table 33. Analysis of variance, regression coefficients and probabilities for yield of weeds (g DM/m^2) for the wet season of 1979.

RESPONSE MEAN	9.4087
ROOT MSE	12.3217
R-SQUARE	0.54979539
COEF OF VARIATION	1.3096

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	4241.0731	0.3493	6.78	0.0003
QUADRATIC	4	302.4015	0.0249	0.50	0.7373
CROSSPRODUCT	6	2131.2885	0.1756	2.34	0.0520
TOTAL REGRESS	14	6674.7831	0.5498	3.14	0.0028

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	5359.8769	206.1491	19.480	0.0001
PURE ERROR	10	105.8258	10.5826		
TOTAL ERROR	36	5465.7027	151.8251		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	10.5303	3.1163	3.38	0.0018
X1	1	-0.34805697	1.1761	-0.30	0.7690
X2	1	-5.0820	1.1778	-4.32	0.0001
X3	1	-4.3078	1.1761	-3.66	0.0008
X4	1	-1.3353	1.1761	-1.14	0.2637
X1*X1	1	1.8024	1.9073	0.95	0.3509
X1*X2	1	0.46330995	0.64418459	0.72	0.4766
X2*X2	1	-1.8809	1.9073	-0.99	0.3306
X1*X3	1	0.66226250	0.61608659	1.07	0.2895
X2*X3	1	2.2286	0.64418459	3.46	0.0014
X3*X3	1	1.2541	1.9073	0.66	0.5150
X1*X4	1	-0.08508750	0.61608659	-0.14	0.8909
X2*X4	1	0.36385477	0.64418459	0.56	0.5757
X3*X4	1	0.14858750	0.61608659	0.24	0.8108
X4*X4	1	-0.97466604	1.9073	-0.51	0.6125

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	393.6798	78.7360	0.52	0.7605
X2	5	4963.6565	992.7313	6.54	0.0002
X3	5	3234.5947	646.9189	4.26	0.0038
X4	5	256.0955	51.2191	0.34	0.8869

Table 34. Analysis of variance, regression coefficients and probabilities for yield of weeds (g DM/m^2) for the dry season of 1979.

RESPONSE MEAN	12.5469
ROOT MSE	18.0158
R-SQUARE	0.72851147
COEF OF VARIATION	1.4359

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	15464.2724	0.3593	11.91	0.0001
QUADRATIC	4	2681.7238	0.0623	2.07	0.1058
CROSSPRODUCT	6	13208.1525	0.3069	6.78	0.0001
TOTAL REGRESS	14	31354.1488	0.7285	6.90	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	11516.3712	442.9374	26.345	0.0001
PURE ERROR	10	168.1283	16.8128		
TOTAL ERROR	36	11684.4995	324.5694		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	6.4747	4.5565	1.42	0.1639
X1	1	-4.6936	1.7196	-2.73	0.0098
X2	1	-9.3174	1.7220	-5.41	0.0001
X3	1	-9.5965	1.7196	-5.58	0.0001
X4	1	0.87423712	1.7196	0.51	0.6143
X1*X1	1	1.7270	2.7807	0.62	0.5396
X1*X2	1	2.6713	0.94187308	2.84	0.0074
X2*X2	1	-1.4397	2.7887	-0.52	0.6088
X1*X3	1	1.8730	0.90079053	2.08	0.0448
X2*X3	1	4.7916	0.94187308	5.09	0.0001
X3*X3	1	5.0483	2.7887	1.81	0.0786
X1*X4	1	-1.1428	0.90079053	-1.27	0.2127
X2*X4	1	-0.55544461	0.94187308	-0.59	0.5591
X3*X4	1	-0.63014167	0.90079053	-0.70	0.4887
X4*X4	1	-1.5126	2.7887	-0.54	0.5909

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	5943.0961	1188.6192	3.66	0.0088
X2	5	20781.2088	4156.2418	12.81	0.0001
X3	5	16974.9107	3394.9821	10.46	0.0001
X4	5	927.6552	185.7310	0.57	0.7203

Table 35. Analysis of variance, regression coefficients and probabilities for yield of weed (kg DM/m^2) for the wet season of 1980.

RESPONSE MEAN	24.2952
ROOT MSE	23.7422
R-SQUARE	0.86301666
COEF OF VARIATION	0.97724156

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	67440.2148	0.4552	29.91	0.0001
QUADRATIC	4	14622.7175	0.0987	6.49	0.0005
CROSSPRODUCT	6	45786.0677	0.3091	13.54	0.0001
TOTAL REGRESS	14	127849	0.8630	16.20	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	19540.7432	751.5670	9.991	0.0003
PURE ERROR	10	752.2400	75.2240		
TOTAL ERROR	36	20292.9832	563.6940		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	7.1080	6.0048	1.18	0.2443
X1	1	-2.8548	2.2662	-1.26	0.2159
X2	1	-20.6103	2.2694	-9.08	0.0001
X3	1	-19.7345	2.2662	-8.71	0.0001
X4	1	7.1496	2.2662	3.15	0.0032
X1*X1	1	1.9100	3.6751	0.52	0.6064
X1*X2	1	0.98748192	1.2413	0.80	0.4315
X2*X2	1	-1.4608	3.6751	-0.40	0.6934
X1*X3	1	0.80295040	1.1871	0.68	0.5031
X2*X3	1	9.9357	1.2413	8.00	0.0001
X3*X3	1	9.9309	3.6751	2.70	0.0104
X1*X4	1	0.22785119	1.1871	0.19	0.8489
X2*X4	1	-3.6453	1.2413	-2.94	0.0058
X3*X4	1	-3.2292	1.1871	-2.72	0.0100
X4*X4	1	-0.32748273	3.6751	-0.09	0.9295

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	1438.1045	287.6209	0.51	0.7666
X2	5	88100.2689	17620.0538	31.26	0.0001
X3	5	69668.8126	13933.7625	24.72	0.0001
X4	5	12309.5691	2461.9138	4.37	0.0033

Table 36. Analysis of variance, regression coefficients and probabilities for visual estimation grass for the wet season of 1978.

RESPONSE MEAN	60.1105
ROOT MSE	10.1617
R-SQUARE	0.18029747
COEF OF VARIATION	0.16904973

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	156.1627	0.0344	0.38	0.8228
QUADRATIC	4	473.4330	0.1044	1.15	0.3506
CROSSPRODUCT	6	187.7741	0.0415	0.30	0.9310
TOTAL REGRESS	14	817.5898	0.1803	0.57	0.8736

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	2492.0233	95.8470	0.782	0.7076
PURE ERROR	10	1225.3102	122.5310		
TOTAL ERROR	36	3717.3335	103.2593		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	57.8547	2.5700	22.51	0.0001
X1	1	-0.47438047	0.96993462	-0.49	0.6277
X2	1	-0.07773862	0.97129312	-0.08	0.9367
X3	1	-0.39320943	0.96993462	-0.41	0.6876
X4	1	-0.79750972	0.96993462	-0.82	0.4164
X1*X1	1	-2.0494	1.5729	-1.30	0.2009
X1*X2	1	0.07748421	0.53125507	0.15	0.8849
X2*X2	1	0.86726673	1.5729	0.55	0.5848
X1*X3	1	-0.53908333	0.50808283	-1.06	0.2957
X2*X3	1	-0.14866983	0.53125507	-0.28	0.7812
X3*X3	1	-0.38273327	1.5729	-0.24	0.8091
X1*X4	1	0.13241667	0.50808283	0.26	0.7959
X2*X4	1	-0.25414845	0.53125507	-0.48	0.6353
X3*X4	1	0.27758333	0.50808283	0.55	0.5882
X4*X4	1	2.5339	1.5729	1.61	0.1159

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	323.2526	64.6505	0.63	0.6809
X2	5	65.7067	13.1413	0.13	0.9853
X3	5	188.0564	37.6113	0.36	0.8696
X4	5	433.9179	86.7836	0.84	0.5300

Table 37. Analysis of variance, regression coefficients and probabilities for visual estimation grass for the dry season of 1978.

RESPONSE MEAN	73.4756
ROOT MSE	6.0598
R-SQUARE	0.72630355
COEF OF VARIATION	0.08247307

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	3107.5442	0.6432	21.16	0.0001
QUADRATIC	4	93.2107	0.0193	0.63	0.6411
CROSSPRODUCT	6	308.6844	0.0639	1.40	0.2410
TOTAL REGRESS	14	3509.4392	0.7264	6.83	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	1016.3421	39.0901	1.279	0.3544
PURE ERROR	10	305.6046	30.5605		
TOTAL ERROR	36	1321.9467	36.7207		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	71.3133	1.5326	46.53	0.0001
X1	1	-1.1309	0.57840717	-1.96	0.0584
X2	1	4.8573	0.57921729	8.39	0.0001
X3	1	1.5184	0.57840717	2.63	0.0126
X4	1	-0.31379940	0.57840717	-0.54	0.5908
X1*X1	1	0.32543681	0.93799285	0.35	0.7306
X1*X2	1	0.01970201	0.31680665	0.06	0.9508
X2*X2	1	1.1727	0.93799285	1.25	0.2193
X1*X3	1	-0.49009213	0.30298820	-1.62	0.1145
X2*X3	1	-0.59456164	0.31680665	-1.88	0.0687
X3*X3	1	-1.0730	0.93799285	-1.14	0.2602
X1*X4	1	0.22422639	0.30298820	0.74	0.4641
X2*X4	1	0.41474540	0.31680665	1.31	0.1988
X3*X4	1	0.01466250	0.30298820	0.05	0.9617
X4*X4	1	-0.15372986	0.93799285	-0.16	0.8707

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	271.3877	54.2775	1.48	0.2211
X2	5	2859.9234	571.9847	15.58	0.0001
X3	5	446.7100	89.3420	2.43	0.0534
X4	5	85.1464	17.0293	0.46	0.8005

Table 38. Analysis of variance, regression coefficients and probabilities for visual estimation grass for the wet season of 1979.

RESPONSE MEAN	79.8126
ROOT MSE	6.8915
R-SQUARE	0.83658645
COEF OF VARIATION	0.08634547

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	6424.3479	0.6140	33.82	0.0001
QUADRATIC	4	214.1237	0.0205	1.13	0.3591
CROSSPRODUCT	6	2114.3441	0.2021	7.42	0.0001
TOTAL REGRESS	14	8752.8157	0.8366	13.16	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	1559.7237	59.9894	3.999	0.0131
PURE ERROR	10	149.9963	14.9996		
TOTAL ERROR	36	1709.7201	47.4922		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	77.4709	1.7429	44.45	0.0001
X1	1	-0.37284439	0.65779293	-0.57	0.5744
X2	1	7.1886	0.65871424	10.91	0.0001
X3	1	2.9444	0.65779293	4.48	0.0001
X4	1	0.00971149	0.65779293	0.01	0.9883
X1*X1	1	-0.57175009	1.0667	-0.54	0.5953
X1*X2	1	-0.63943240	0.36028803	-1.77	0.0844
X2*X2	1	1.5741	1.0667	1.48	0.1487
X1*X3	1	-0.87108750	0.34457301	-2.53	0.0160
X2*X3	1	-2.0750	0.36028803	-5.76	0.0001
X3*X3	1	-1.7897	1.0667	-1.68	0.1021
X1*X4	1	0.40212917	0.34457301	1.17	0.2509
X2*X4	1	0.24119199	0.36028803	0.67	0.5075
X3*X4	1	0.00449583	0.34457301	0.01	0.9897
X4*X4	1	0.82408324	1.0667	0.77	0.4448

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	592.5914	118.5183	2.50	0.0486
X2	5	7561.2152	1512.2430	31.84	0.0001
X3	5	2417.7582	483.5516	10.18	0.0001
X4	5	116.6154	23.3231	0.49	0.7807

Table 39. Analysis of variance, regression coefficients and probabilities for visual estimation grass for the dry season of 1979.

RESPONSE MEAN	77.7099
ROOT MSE	8.3315
R-SQUARE	0.87537383
COEF OF VARIATION	0.10721296

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	13662.9551	0.6814	49.21	0.0001
QUADRATIC	4	312.1462	0.0156	1.12	0.3604
CROSSPRODUCT	6	3577.1864	0.1784	8.59	0.0001
TOTAL REGRESS	14	17552.2877	0.8754	18.06	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	2237.8187	86.0699	3.297	0.0263
PURE ERROR	10	261.0844	26.1084		
TOTAL ERROR	36	2498.9031	69.4140		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	73.8873	2.1072	35.06	0.0001
X1	1	0.21486152	0.79524585	0.27	0.7886
X2	1	9.6975	0.79635968	12.18	0.0001
X3	1	6.3346	0.79524585	7.97	0.0001
X4	1	-0.19943027	0.79524585	-0.25	0.8034
X1*X1	1	-0.30512484	1.2896	-0.24	0.8143
X1*X2	1	-0.60567784	0.43557409	-1.39	0.1729
X2*X2	1	2.2365	1.2896	1.73	0.0914
X1*X3	1	-0.26963333	0.41657525	-0.65	0.5216
X2*X3	1	-3.0189	0.43557409	-6.93	0.0001
X3*X3	1	-2.0239	1.2896	-1.57	0.1253
X1*X4	1	0.24034167	0.41657525	0.58	0.5676
X2*X4	1	0.39065051	0.43557409	0.90	0.3758
X3*X4	1	-0.03567500	0.41657525	-0.09	0.9322
X4*X4	1	0.42404183	1.2896	0.33	0.7442

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	191.6928	38.3386	0.55	0.7355
X2	5	14132.3564	2826.4713	40.72	0.0001
X3	5	6213.5553	1242.7111	17.90	0.0001
X4	5	86.9630	17.3926	0.25	0.9368

Table 40. Analysis of variance, regression coefficients and probabilities for visual estimation grass for the wet season of 1980.

RESPONSE MEAN	79.6997
ROOT MSE	8.8092
R-SQUARE	0.70924908
COEF OF VARIATION	0.11052931

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	19927.9405	0.6474	64.20	0.0001
QUADRATIC	4	2193.1120	0.0712	7.07	0.0003
CROSSPRODUCT	6	5868.9576	0.1907	12.60	0.0001
TOTAL REGRESS	14	27990.0101	0.9092	25.76	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	2674.2102	102.8542	8.612	0.0006
PURE ERROR	10	119.4346	11.9435		
TOTAL ERROR	36	2793.6449	77.6012		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	78.3931	2.2280	35.19	0.0001
X1	1	0.67629662	0.84083794	0.80	0.4265
X2	1	12.0220	0.84201562	14.28	0.0001
X3	1	7.6869	0.84083794	9.14	0.0001
X4	1	-1.5528	0.84083794	-1.85	0.0730
X1*X1	1	-0.62127855	1.3636	-0.46	0.6514
X1*X2	1	-0.15065786	0.46054591	-0.33	0.7455
X2*X2	1	4.5662	1.3636	3.35	0.0019
X1*X3	1	-0.37193849	0.44045785	-0.84	0.4040
X2*X3	1	-3.9118	0.46054591	-8.49	0.0001
X3*X3	1	-6.4338	1.3636	-4.72	0.0001
X1*X4	1	-0.09173611	0.44045785	-0.21	0.8362
X2*X4	1	0.74262532	0.46054591	1.61	0.1156
X3*X4	1	0.06593056	0.44045785	0.15	0.8818
X4*X4	1	1.4412	1.3636	1.06	0.2976

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	125.7336	25.1467	0.32	0.8952
X2	5	22755.8180	4551.1636	58.65	0.0001
X3	5	11147.1645	2229.4329	28.73	0.0001
X4	5	454.1268	90.8254	1.17	0.3426

Table 41. Analysis of variance, regression coefficients and probabilities for visual estimation legume for the wet season of 1978.

RESPONSE MEAN	36.2464
ROOT MSE	9.2274
R-SQUARE	0.12747715
COEF OF VARIATION	0.25463003

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	43.4822	0.0124	0.13	0.9714
QUADRATIC	4	157.4084	0.0448	0.46	0.7631
CROSSPRODUCT	6	247.1394	0.0703	0.48	0.8161
TOTAL REGRESS	14	448.0301	0.1275	0.38	0.9737

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	1969.3390	75.7438	0.690	0.7852
PURE ERROR	10	1097.2222	109.7222		
TOTAL ERROR	36	3066.5612	85.1823		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	37.2815	2.3343	15.97	0.0001
X1	1	0.06829446	0.88095255	0.08	0.9386
X2	1	0.18466557	0.88218642	0.21	0.8354
X3	1	0.38275024	0.88095255	0.43	0.6665
X4	1	0.28930290	0.88095255	0.33	0.7444
X1*X1	1	1.3943	1.4286	0.98	0.3356
X1*X2	1	0.03757289	0.48251759	0.08	0.9384
X2*X2	1	0.14428096	1.4286	0.10	0.9201
X1*X3	1	0.44983333	0.46147117	0.97	0.3362
X2*X3	1	-0.06557337	0.48251759	-0.14	0.8927
X3*X3	1	-0.68905238	1.4286	-0.48	0.6325
X1*X4	1	-0.17233333	0.46147117	-0.37	0.7110
X2*X4	1	0.35219874	0.48251759	0.73	0.4702
X3*X4	1	-0.51683333	0.46147117	-1.12	0.2701
X4*X4	1	-1.3141	1.4286	-0.92	0.3638

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	175.4082	35.0816	0.41	0.8374
X2	5	52.1961	10.4392	0.12	0.9865
X3	5	223.6890	44.7380	0.53	0.7556
X4	5	263.5059	52.7012	0.62	0.6863

Table 42. Analysis of variance, regression coefficients and probabilities for visual estimation legume for the dry season of 1978.

RESPONSE MEAN	24.7270
ROOT MSE	5.6336
R-SQUARE	0.69257255
COEF OF VARIATION	0.22783308

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	2304.0419	0.6199	18.15	0.0001
QUADRATIC	4	50.1518	0.0135	0.40	0.8108
CROSSPRODUCT	6	219.7669	0.0591	1.15	0.3521
TOTAL REGRESS	14	2573.9606	0.6926	5.79	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	848.0583	32.6176	1.108	0.4558
PURE ERROR	10	294.5023	29.4502		
TOTAL ERROR	36	1142.5606	31.7378		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	26.1128	1.4248	18.33	0.0001
X1	1	1.0483	0.53773255	1.95	0.0591
X2	1	-4.1701	0.53848570	-7.74	0.0001
X3	1	-1.4325	0.53773255	-2.66	0.0115
X4	1	0.23165654	0.53773255	0.43	0.6692
X1*X1	1	-0.53540682	0.87203152	-0.61	0.5431
X1*X2	1	-0.01019712	0.29452825	-0.03	0.9726
X2*X2	1	-0.71596238	0.87203152	-0.82	0.4170
X1*X3	1	0.37429583	0.28168154	1.33	0.1923
X2*X3	1	0.47552347	0.29452825	1.61	0.1151
X3*X3	1	0.50452373	0.87203152	0.58	0.5665
X1*X4	1	-0.22139306	0.28168154	-0.79	0.4370
X2*X4	1	-0.40760255	0.29452825	-1.38	0.1749
X3*X4	1	-0.03769028	0.28168154	-0.13	0.8943
X4*X4	1	0.71389873	0.87203152	0.82	0.4184

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	218.1588	43.6318	1.37	0.2567
X2	5	2083.4265	416.6853	13.13	0.0001
X3	5	316.7246	63.3449	2.00	0.1028
X4	5	102.2545	20.4509	0.64	0.6674

Table 43. Analysis of variance, regression coefficients and probabilities for visual estimation legume for the wet season of 1979.

RESPONSE MEAN	15.7985
ROOT MSE	5.1457
R-SQUARE	0.75420910
COEF OF VARIATION	0.32163841

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	2308.7418	0.6157	22.55	0.0001
QUADRATIC	4	165.6596	0.0427	1.56	0.2049
CROSSPRODUCT	6	371.8275	0.0958	2.34	0.0520
TOTAL REGRESS	14	2926.2289	0.7543	7.89	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	806.2357	31.0091	2.110	0.1083
PURE ERROR	10	146.9881	14.6988		
TOTAL ERROR	36	953.2238	26.4784		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	19.5268	1.3014	15.00	0.0001
X1	1	0.91149842	0.49116131	1.86	0.0717
X2	1	-4.2055	0.49184923	-8.55	0.0001
X3	1	-0.20111820	0.49116131	-0.41	0.6846
X4	1	0.44520833	0.49116131	0.91	0.3707
X1*X1	1	-0.07376085	0.79650775	-0.09	0.9267
X1*X2	1	0.26799775	0.26902013	1.00	0.3258
X2*X2	1	-1.0529	0.79650775	-1.32	0.1945
X1*X3	1	0.47575417	0.25728603	1.85	0.0727
X2*X3	1	0.62321641	0.26902013	2.32	0.0263
X3*X3	1	0.79082248	0.79650775	0.99	0.3274
X1*X4	1	-0.34779583	0.25728603	-1.35	0.1849
X2*X4	1	-0.40614583	0.26902013	-1.51	0.1398
X3*X4	1	-0.10216250	0.25728603	-0.40	0.6937
X4*X4	1	-0.60292752	0.79650775	-0.76	0.4540

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	298.8451	59.7690	2.26	0.0695
X2	5	2232.3011	446.4602	16.86	0.0001
X3	5	264.9832	52.9966	2.00	0.1019
X4	5	134.3538	26.8708	1.01	0.4233

Table 44. Analysis of variance, regression coefficients and probabilities for visual estimation legume for the dry season of 1979.

RESPONSE MEAN	16.2682
ROOT MSE	7.9953
R-SQUARE	0.67957192
COEF OF VARIATION	0.49147010

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	3462.5520	0.4821	13.54	0.0001
QUADRATIC	4	1160.7140	0.1616	4.54	0.0045
CROSSPRODUCT	6	257.4282	0.0358	0.67	0.6735
TOTAL REGRESS	14	4880.6941	0.6796	5.45	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	2127.0230	81.8086	4.694	0.0071
PURE ERROR	10	174.2956	17.4296		
TOTAL ERROR	36	2301.3185	63.9255		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	24.8118	2.0221	12.27	0.0001
X1	1	1.5158	0.76315906	1.99	0.0547
X2	1	-4.5445	0.76422795	-5.95	0.0001
X3	1	-1.0391	0.76315906	-1.36	0.1818
X4	1	0.40612913	0.76315906	0.53	0.5979
X1*X1	1	-0.52515726	1.2376	-0.42	0.6738
X1*X2	1	-0.37588526	0.41799943	-0.90	0.3745
X2*X2	1	-1.9835	1.2376	-1.60	0.1177
X1*X3	1	-0.44431250	0.39976716	-1.11	0.2738
X2*X3	1	0.25327836	0.41799943	0.61	0.5484
X3*X3	1	-0.33505310	1.2376	-0.27	0.7881
X1*X4	1	0.17687083	0.39976716	0.44	0.6608
X2*X4	1	-0.49797649	0.41799943	-1.19	0.2413
X3*X4	1	0.01204583	0.39976716	0.03	0.9761
X4*X4	1	-0.18140726	1.2376	-0.15	0.8843

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	362.2990	72.4598	1.13	0.3605
X2	5	2632.6178	526.5236	8.24	0.0001
X3	5	205.2511	41.0502	0.64	0.6691
X4	5	107.0429	21.4086	0.33	0.8884

Table 45. Analysis of variance, regression coefficients and probabilities for visual estimation legume for the wet season of 1980.

RESPONSE MEAN	11.1137
ROOT MSE	6.3540
R-SQUARE	0.75238183
COEF OF VARIATION	0.57173128

REGRESSION	DF	TYPE I SS	R-SQUARE	F-RATIO	PROB
LINEAR	4	2707.3383	0.4612	16.76	0.0001
QUADRATIC	4	1578.0869	0.2689	9.77	0.0001
CROSSPRODUCT	6	130.8678	0.0223	0.54	0.7740
TOTAL REGRESS	14	4416.2930	0.7524	7.81	0.0001

RESIDUAL	DF	SS	MEAN SQUARE	F-RATIO	PROB
LACK OF FIT	26	1384.4804	53.2492	7.720	0.0009
PURE ERROR	10	68.9763	6.8976		
TOTAL ERROR	36	1453.4567	40.3738		

PARAMETER	DF	ESTIMATE	STD DEV	T-RATIO	PROB
INTERCEPT	1	19.3163	1.6070	12.02	0.0001
X1	1	0.41117677	0.60649572	0.68	0.5021
X2	1	-4.1517	0.60734518	-6.84	0.0001
X3	1	0.23489952	0.60649572	0.39	0.7008
X4	1	0.55973235	0.60649572	0.92	0.3622
X1*X1	1	0.32311172	0.98354356	0.33	0.7444
X1*X2	1	-0.22612757	0.33219139	-0.68	0.5004
X2*X2	1	-3.8602	0.98354356	-3.92	0.0004
X1*X3	1	0.01833929	0.31770189	0.06	0.9543
X2*X3	1	-0.07016130	0.33219139	-0.21	0.8339
X3*X3	1	1.7398	0.98354356	1.77	0.0854
X1*X4	1	0.09626389	0.31770189	0.30	0.7636
X2*X4	1	-0.34437662	0.33219139	-1.04	0.3068
X3*X4	1	0.39726389	0.31770189	1.25	0.2192
X4*X4	1	-1.1352	0.98354356	-1.15	0.2560

FACTOR	DF	SS	MEAN SQUARE	F-RATIO	PROB
X1	5	37.0387	7.4077	0.18	0.9670
X2	5	2645.3108	529.0622	13.10	0.0001
X3	5	196.0710	39.2142	0.97	0.4484
X4	5	180.9817	36.1963	0.90	0.4939

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BIOGRAPHICAL SKETCH

Raul A. Santillan was born December 6, 1943, in Riobamba, Chimborazo province, Ecuador, to Rigoberto and Itala Santillan. From May 1962 to January 1968 he attended the Universidad de Guayaquil, Ecuador, and received the Ingeniero Agronomo degree. For six months he worked in the Programa Nacional del Banano and in August of 1968 he joined the Instituto Nacional de Investigaciones Agropecuarias (INIAP), working in tropical pastures at the Extacion Experimental Pichilingue. In 1972 he was awarded a grant to receive a year's training in cattle production at the Centro Internacional de Agricultural Tropical (CIAT) in Cali, Colombia. In 1974 he received the Master of Science degree in agriculture. In 1981 he continued his studies toward the degree of Doctor of Philosophy in agronomy.

Raul A. Santillan is married to the former Maggie Moreno and they have two daughters, Alexandra and Carolina. The author is a member of the Asociacion Ecuatoriana de Produccion Animal and Asociacion Latinoamericana de Produccion Animal.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of shcolarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

G. O. Mott

G. O. Mott, Chairman
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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